

# **BUSINESS PROCESSES AND STRATEGIC FRAMEWORK FOR INSPECTION IN REMANUFACTURING**

**Submitted by**

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Mark Errington

## **ABSTRACT**

A crucial stage of the remanufacturing process is the inspection procedure. Surveys carried out in the automotive remanufacturing sector show that the industry is concerned about its need for such a large amount of specialist skills. Despite this, there has been little research into what is actually involved in the inspection process and what different strategies are used in different companies carrying out remanufacturing operations.

This thesis presents case based research that was carried out on the inspection procedures of sixteen companies. These included companies from all industries ranging from those in the automotive and defence industries, to those in consumer electronics and IT. The cases range from small companies remanufacturing a few units per month to those with established remanufacturing production lines.

This project has created two key contributions to theory. The first is a theory for remanufacturing strategy. A framework for remanufacturing strategy has been produced showing how different strategies are used to remanufacture items with different characteristics. The second is a generic inspection process which breaks down each inspection procedure within remanufacturing to its main objectives and methods.

These, practical and applicable, contributions are of vital interest to researchers who can use them to enhance their knowledge of inspection procedures within remanufacturing and will act as a road map for future research into this new and exciting area.

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# **CHAPTER 1: INTRODUCTION TO THE FIELD OF RESEARCH**

This chapter gives an introduction to the area of take back laws and producer responsibility. It is this legislation which is likely to drive interest in remanufacturing. It is this anticipated boost in interest in remanufacturing which has led to the need for formal models of the processes within remanufacturing and frameworks such as the ones which were developed in this project. These models and frameworks can be used as an aid to understanding and as a tool for designing and improving remanufacturing processes. This chapter will show how remanufacturing provides a solution to compliance with extended producer responsibility legislation and show why it is anticipated that many producers will seek to develop remanufacturing processes in the near future.

## **1.1 Introduction**

During the late 1990s and early 2000s there has been an increasing amount of legislation devoted to encouraging manufacturers to be more environmentally friendly. The emergence of this new legislation has been reported time and time again in many popular Operations Management journals. This has included papers from researchers including Jayaraman, Guide et al. (1999); Nagel and Meyer (1999); Goggin, Reay et al. (2000); Ferguson and Browne (2001); Childe (2002); Guide, Jayaraman et al. (2003); Krikke, le Blanc et al. (2004) and Toffel (2004). The main aim of the majority of this legislation is to make the producers of waste responsible for its treatment and disposal. These so called producer responsibility or take-back laws have recently become popular with governments around the world and similar legislation has been introduced in China, described by Chen (2004), Japan, and some states of the USA as discussed by Hieronymi (2004). In Japan the legislation has been in force for almost a decade and some of the major equipment manufacturers are reporting profits from their recycling businesses. The legislation has taken many forms. In Japan, for example, Ogushi and Kandlikar (2007) report that the

producer responsibility, or ‘take-back’ laws initially only applied to air conditioners, refrigerators (including freezers), televisions, and washing machines..

## **1.2 Take Back Law in the EU**

There are four main areas of legislation which could fall under the heading of take back laws. These are;

- The Waste Electric and Electronic Equipment (WEEE) Directive (2002/96/EC)
- The End of Life Vehicles Directive (2000/53/EC)
- The Batteries and Accumulators Council Directive (91/157/EEC)
- The Packaging and Packaging Waste Directive (94/62/EC)

In each of these directives, requirements are laid out for member states to produce legislation that requires the producers of the above mentioned products to set up systems for the collection and sorting of the items covered by the legislation and to fund their disposal subject to minimum recycling rates.

All the legislation listed above requires producers to recover and dispose of their products subject to minimum recycling and recovery limits that are contained within the legislation. The legislation states that the recycling and recovery limits for all of these laws will be under regular review and it has been made clear that the limits will get more difficult to meet in the future.

Canning (2006) concludes that a good solution to this problem, from an environmental perspective, is to reuse items. This cannot always be done, but as concluded by Mayers,

France et al. (2002) it is thought to be an extremely cost effective way of meeting the requirements of the legislation.

### **1.3 Methods for Compliance**

Ease of compliance with these laws depends largely on the nature of the products in question. However, there are some similarities between the groups of products affected by each of the laws. The Packaging and Packaging Waste Directive and the Batteries and Accumulators Directive offer a clear set of solutions to compliance. In general the items taken back can be reused directly, recycled on a materials level or incinerated with energy recovery.

Matthews (2004) details a case of Quantum corporation that managed to reduce its packaging use by 80% through implementation of a reusable packaging system. In his case study he implies that all packaging used becomes waste immediately after its use. This means that the 80% reduction in use of packaging materials also led to a reduction in packaging waste of 80% leading to substantial materials and waste disposal savings.

For simple packaging, once it is damaged it must be disposed of. In Matthews (2004) case study at Quantum corporation this is done through materials recycling. However in some cases once packaging becomes damaged it can be repaired and put back into use. Kopicki (1993) details a wooden pallet take back system which involves repair of damaged pallets. The pallets are specially designed to prolong their life and facilitate easy repair. Compared to other packaging, for example corrugated cardboard boxes, pallets are complex items that lend themselves easily to repair.

Batteries are more complex products, however they are designed in such a way that disassembly is difficult and so materials recovery is option the only viable option. Schultmann, Engels et al. (2003) detail a battery take back system for sorting and recycling used batteries. The most environmentally friendly method of disposal in this chain is materials recycling. Schultmann, Engels et al. (2003) report that for some batteries, hazardous waste landfill is currently the only option.

For end of life vehicles and WEEE the solutions become more varied. This is largely due to the complexity of such products. Many of the techniques employed in take back systems, such as repair, refurbishment and remanufacturing, have been used for many years. A discussion of the definitions for these terms can be found in section 1.6.

Compliance with the recycling targets is likely to be a relatively easy process. It is reported in Gungor and Gupta (1999) that the current European model Ford Mondeo, developed in 1994, is 85% recyclable. A report produced by the EU (2001) states that the Dutch government is seeking to increase its minimum recycling limits for end of life vehicles ahead of the implementation of the new limits due in 2015. In the report from the EU (2001) the Dutch government acknowledges that the cost to the consumer even to meet the current limits is likely to increase. In the report it is stated that this is due to the increasing use of lightweight, high performance composite plastics currently being used in the production of modern cars.

It has been seen from the Dutch example that meeting the initial recovery and recycling limits set by the EU can be straight forward for industry. The limits have been exceeded using existing recycling technology and networks.

The recovery and recycling limits set for the next round of increases, which according to Gerrard and Kandlikar (2007) are due to come into force in 2015, are likely to be much more difficult to meet using the materials recycling approach. Ferrer and Whybark (2000) state that materials recycling is the least favourable product recovery option from an economical and ecological standpoint is recycling. As the new EU targets become more difficult to reach using materials recycling techniques, producers may have to look at other product recovery options. These options will be discussed in section 1.5.2.

#### **1.4 Compliance Choices**

Kollberg (2003) describes the two main choices for companies having to comply with take back legislation. These are to join a compliance scheme or to set up separate product take back systems. Table 1 shows a brief summary of some of the positive and negative aspects of these two choices.

	<b>Positive Aspects</b>	<b>Negative Aspects</b>
<b>Join Compliance Scheme</b>	Economies of scale are realised by contractor reducing cost to producers	Only recovery options are energy recovery and materials recycling. Both of these options lose the product and its components added value
	Little work is required by producer	Any design improvements, for example design for disassembly, are unlikely to lead to direct savings
<b>Set up own product take back system</b>	Residual value of components and products can be recovered	High initial and running costs
	Design improvements lead directly to cost savings	Probably not currently a core competency
	If conditions are correct then can lead to additional revenue stream	Requires changes to structure of organisation

**Table 1 - Positive and Negative Aspects to the Two Compliance Options Adapted From Kollberg (2003)**

It may be the case that, from the point of view of many small companies, joining a compliance scheme is the only option. The costs of running their own collection systems would far outweigh the value that could be recovered from their end of life products. For larger companies with potentially high value end of life products the benefits of setting up separate product take back networks in the long term can be huge. In essence the option to join a compliance scheme for a larger producer is a short term or reactive approach. In contrast the setting up of a separate product take back system could be described as a long term or value seeking approach. The following section describes some examples of companies that have taken this long term view and are attempting to seek additional value from the take back of their used products.

## **1.5 Compliance as a Profit Centre**

Many companies are beginning to realise that reusing their old products as new can be used as a highly efficient business model. Stock, Speh et al. (2002) discuss how treating returned goods as goods for sale and designing efficient routes for returned products businesses have begun to recover money through the return of products. Webster and Mitra (2007) details how the new take back laws have the potential to make this an even more profitable process for even more products. It is stated in both the WEEE Directive, EU (2003), and the End of Life Vehicles Directive, EU (2000), that reuse of products and components is the preferred treatment option for end of life products that fall under the remit of the legislation. The directives do not, however, set minimum limits for reuse.

According to Kopicki (1993) there are three phases in the development of reuse and recycling programs. These are stated as reactive, proactive and value seeking. Companies described by Kopicki (1993) as reactive phase only implement schemes in order to comply with existing legislation. Proactive companies aim to exceed current environmental legislation targets and to comply with new legislation before it comes into force. Kopicki (1993) also describes the value seeking approach. This shows great maturity of environmental programs where environmental performance is considered to be a competitive tool. Kopicki (1993) also states that it is usual for value seeking companies to reduce costs alongside environmental impact.

Good examples of value seeking companies, provided by Linton and Jayaraman (2005), include Kodak and Xerox. These companies have successfully implemented take back and reuse schemes for a large percentage of their products sold. According to Sanchoy K. Das



(2000) Xerox estimates that it will reuse 60% of the parts from all four million of its photocopiers that reach their end of life annually. In its environmental report Kodak (2000) states that its current disposable camera is 76 to 90% reusable or recyclable. The products produced by both of these companies are probably subject to the WEEE directive (Kodak's cameras without flash are probably exempt). Xerox photocopiers are category 3 items and disposable cameras fall into category 4. Both of these categories have a minimum reuse and recycling target of 65%. Through reuse alone Kodak will exceed this target and with a small amount of materials recycling so will Xerox.

Kopicki (1993) describes the many benefits of value seeking schemes. He states that they can lead to huge savings due to a reduction in virgin materials use and they can strengthen the company's environmental performance. In addition to this Kopicki (1993) states that very little organisational or product change is required in order to comply with future environmental legislation.

Kodak has agreements in place with film developers to return used cameras to them. Toffel (2004) describes how Xerox leases machines to a customer rather than selling them. This means that it has complete control over the return of the copier and is also responsible for maintaining it in a good condition. Leasing is an area in which Xerox along with other companies are actively looking to expand. Another company discussed by Toffel (2004) which leases its products is Interface, a manufacturer of floor tiles. Krikke, le Blanc et al. (2004) describe how Océ, an international document processing firm is also using a similar approach to aid its product recovery activities.

The importance of this aspect of product take back was identified by Vandermerwe and Oliff (1991). They concluded that one of the key priorities for a company to meet the “corporate challenges in an age of reconsumption” was to;

*“Develop new selling concepts, more akin to leasing than to ownership.”*

It could be said that all of the companies mentioned above have been actively developing these concepts. Thierry, Salomon et al. (1995) describe how Kodak essentially charges for the use of its disposable cameras on a film by film basis whereas many photocopier leasing agreements charge on a copy by copy basis.

### *1.5.1 Reverse Supply Chains*

Take back of used or faulty products require a reverse supply chain. The council of logistics management defines a reverse supply chain as;

*“A specialized segment of logistics focusing on the movement and management of products and resources after the sale and after delivery to the customer. Includes product returns for repair and/or credit.”*

The reverse supply chain starts with the customer and ends with either the safe disposal of the product or the product returning to another consumer. Disposal options identified by the EU (2003) are as follows; **reuse** of components, parts, or entire products, **recycling** of materials, **recovery** of embodied energy through incineration and disposal through land filling or incineration.

It appears that reverse logistics will become an area with increasing importance for manufacturers. Even without the introduction of take back laws, return rates of products for reasons other than the product reaching its end of life are very high. Blumberg (2005) reports that some products are being returned at rates of up to 29% with the majority of

these returns having no fault found after inspection. It is reported by Stock, Speh et al. (2002) that companies are starting to realise that an efficient reverse supply chain is almost as important as their forward supply chain.

Guide Jr. and Van Wassenhove (2002) describe how a typical reverse supply chain can be divided into five main tasks. Starting with the product in the hands of the consumer, these are as follows;

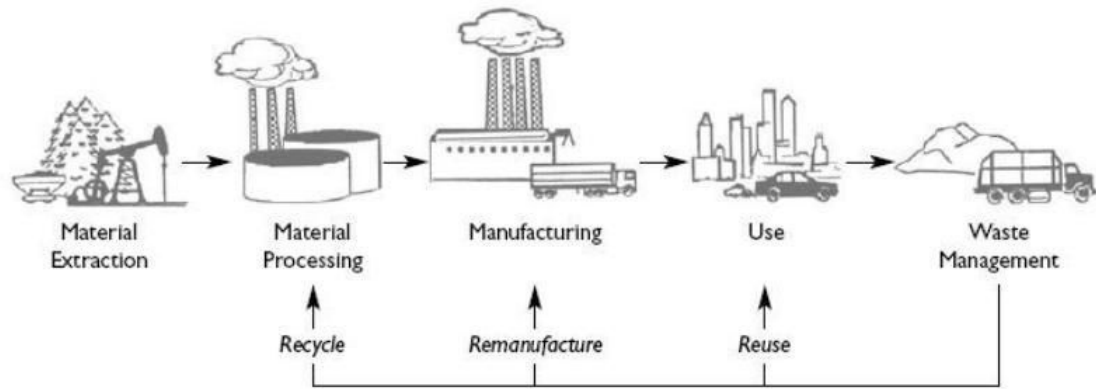
- Product Acquisition
- Reverse Logistics
- Inspection and Disposition
- Reconditioning
- Distribution and Sales

As mentioned earlier, during a discussion of the work by Stock, Speh et al. (2002), companies that have successfully mastered these areas of expertise have started to gain a significant competitive advantage. Finding ways to complete these tasks efficiently is the key to a successful implementation of a reverse supply chain.

### *1.5.2 The Closed Loop Supply Chain*

There is a large amount of literature that describes the concept of a closed loop supply chain. These include papers by Hayes and Pisano (1994); Jayaraman, Guide et al. (1997); Jayaraman, Guide et al. (1999); Guide, Harrison et al. (2003); Guide and Van Wassenhove (2003); Schultmann, Engels et al. (2003) and French and LaForge (2006). In this specialised supply chain at least part of the product continuously loops from customer to manufacturer to customer. Product materials, parts, components or in some cases the whole

product are returned to the manufacturer who uses them to make new products and sells them again to the customer. The following diagram shows one interpretation of this system.



**Figure 1 - Closed Loop Supply Chain taken from Matthews (2004)**

The model shown in the diagram shows 100% recovery of products, parts and materials. In reality 100% recovery of products is almost impossible. There are also limits to how many times a part, component or material can be reused before it is no longer an economically or ecologically positive option. Geyer and Jackson (2004) describe how the amount of virgin materials required depends on the material in question and the products that are to be made from it. In the case of steel this can be very low indeed.

Jayaraman, Guide et al. (1999) and Krikke, le Blanc et al. (2004) state that in order for the reverse supply chain to be optimised it must be totally integrated with the forward supply chain. This is of particular importance when parts from used products are used in the manufacture of new ones.

There are different reasons for a product to be returned and different routes for these through the closed loop supply chain. It has been reported by Krikke, le Blanc et al. (2004) that there are four distinct types of returns in the reverse supply chain. These are:

- End of Life Returns – These are items that are now obsolete and are returned due to legislative requirements.
- End of Use Returns – These are items that are no longer of any use to the consumer. These are returned because of the end of a lease or traded in for a new model.
- Commercial Returns – These items are usually new and are returned due to overstock or a customer deciding against the purchase of the item.
- Re-Usable Items – These are items that facilitate the use of a product but are not the product themselves such as milk bottles or pallets.

Krikke, le Blanc et al. (2004) state that the differences between these types of returns should not be ignored. They go on to state how they should be sent around the most appropriate closed loop supply chain. Some examples of the most appropriate choices for such products are as follows:

- End of Life Returns – Mostly recycle, some remanufacturing or reuse of components as spares.
- End of Use Returns – Mostly remanufacture, some reuse in secondary markets.
- Commercial Returns – Reuse directly if not faulty.
- Re-Usable Items – Reuse or remanufacture as necessary

Some authors including Blackburn, Guide Jr. et al. (2004) and Krikke, le Blanc et al. (2004) conclude that each of these return types has different requirements of a supply chain. A

high value, potentially high depreciation rate, reusable product should be returned to market as quickly as possible whereas where an item is simply destined for materials recycling a highly efficient but slow supply chain is likely to be most suitable. Blackburn, Guide Jr. et al. (2004) have written a paper in which they describe methods for determining the most relevant and cost effective closed loop supply chain for a range of products. They conclude that rapid supply chains are more suited to high value items which deteriorate quickly whereas high efficiency supply chains are more cost effective for low value non-deteriorating goods.

## **1.6 Remanufacturing and other Material Recovery Opportunity**

### **Definitions**

This chapter has outlined closed loop supply chains and their environmental benefits. This section will discuss the different terminology used to describe these different processes and will conclude with the definition that will be used for remanufacturing in the context of this research.

A material recovery opportunity, or MRO, is defined by Johnson and Wang (1995) as “*an opportunity to reclaim post-consumer products for recycling, remanufacturing and re-use.*”

It is a way in recovering material and hence value from an end of life or end of use product. This can be through recycling but also through higher level operations such as remanufacturing, refurbishing and repair.

Definitions for remanufacturing have emerged from the sectors in which it is most mature. In these sectors, remanufacturing is typically carried out on mechanical items which have often failed due to wear out. The definition for Remanufacturing provided by the

Automotive Parts Rebuilders Association APRA (2008), which was established in 1941, appears to confirm this. It states that:

*“remanufacturing is the renovation of used vehicle parts in accordance with the generally accepted state of the art so that they can perform their function similar to new..... remanufacturing regularly consists of dismantling the used aggregate into its components, checking these components, repairing defective components, cleaning all components, reassembling the aggregate, readjusting as necessary, and submitting the product to a final test.”*

Several terms have been published for material recovery opportunities which appear to mean different things to different organisations. The table below shows an overview of terms that can be used interchangeably with remanufacturing as outlined by associations established to assist the industry. In addition to this the table also shows terms that are not considered to be synonymous with remanufacturing by the same organisations.

	<b>Remanufacturing</b>	<b>Not Remanufacturing</b>
<b>The Centre for Remanufacturing and Reuse, UK</b> www.remanufacturing.org.uk	(No other word used)	Reconditioning Refurbishing Overhauling
<b>The Remanufacturing Institute, USA</b> www.reman.org	Rebuilt	Recycled Repaired Restored Reconditioned Used
<b>Automotive Parts Rebuilders Association US &amp; Europe</b> www.apra.org	Rebuilt	Recycled Repaired Restored Reconditioned Used
<b>Code of practice for remanufacture of spark and compression ignition engines BSI (2002)</b>	Reconditioning	Exchange  Factory Rebuilt Repaired
<b>Remanufacturing: The Ultimate form of Recycling Steinhilper (1998)</b>	Rebuilding Refurbishing Reconditioning Overhauling	----- No mention

**Table 2 - Interchangeable Terms for Remanufacturing**

It can be seen from Table 2 that the different organisations have different and often contrasting opinions about the term remanufacturing. Many different terms are used by different organisations to mean remanufacturing. It is thought that this may often be due to historical reasons. In the book Remanufacturing: The Ultimate Form of Recycling makes the comment that the term remanufacturing is starting to become distinctly different from other material recovery opportunities. Steinhilper (1998) states that remanufacturing is



becoming the standard term for restoring used products to ‘like new’ condition. The more recent references in Table 2 seem to show the acceptance of this definition with a clear distinction between remanufacturing and other material recovery opportunities. The only exceptions to this are the terms reconditioning in the UK and rebuilding in the USA. The Automotive Parts Rebuilders Association prefers to use the term “rebuilt” as it gives more description about what process is carried out on the product. This is perhaps the same reason as why reconditioning has been given the same standing as remanufacturing by the BSI (2002) in the British standard for engine remanufacturing.

#### *1.6.1 Other Material Recovery Opportunity Definitions*

There appears to be a need for more robust definitions for material recovery opportunities. This problem has been addressed several times during the 1990s by various organisations and researchers across the world.

Thierry, Salomon et al. (1995) have made an attempt to define the processes depending on the level of disassembly required in order for an operation to be carried out. A table of these definitions is shown in Table 3.

	<b>Level of Disassembly</b>	<b>Quality Requirements</b>	<b>Resulting Product</b>
Repair	To product level	Restore product to working order	Some parts fixed or replaced by spares
Refurbishing	To module level	Inspect all critical modules and upgrade to specified quality level	Some modules repaired/ replaced; potential upgrade
Remanufacturing	To part level	Inspect all modules and parts and upgrade to as new quality	Used and new modules/parts combined into new product; potential upgrade
Cannibalization	Selective retrieval of parts	Depends on process in which parts are reused	Some parts reused; remaining product recycled/disposed
Recycling	To materials level	High for production of original parts; less for other parts	Materials reused to produce new parts

**Table 3 - Return to Market Definitions adapted from Thierry, Salomon et al. (1995)**

These definitions appear to work well however it is assumed that the failed component in the case of repair is easily accessible. This may be the case for a repair such as a fuse replacement but is rarely the case for components which are known to wear. It may not be possible to access these without a more extensive amount of disassembly. This is also unlikely to be the case when the component that caused the product failure was not expected to fail. The module level disassembly level for refurbishing is also not always correct. Likewise Remanufacturing does not necessarily require complete disassembly however this is more often than not the case. King, Burgess et al. (2006) comment that the quality levels of different material recovery opportunities are what is most important from a customer's perspective.

The European Working Group on Reverse Logistics, RevLog (2008), has produced a set of definitions for the five main material recovery opportunities. These are as follows;

**Direct Reuse** *This type of recovery involves products which do not receive repair or upgrading but are cleaned and brought to a state where they can be directly reused by the customer. Examples are pallets, bottles, etc.*

**Materials recycling** *In this type of recovery, the product does not retain its functionality. The purpose is to use some or all of the materials from the returned goods. The recovered materials may be utilized in the production process of the original product or may be inputs of other industries.*

**Repair** *The product/component is brought into the working state after this recovery operation. The quality of the repaired good is generally lower than the quality of a new good.*

**Refurbishing** *The product/component is upgraded such that it meets higher quality and/or operational standards than the original product.*

**Remanufacturing** *In this type of recovery operation, the products are completely disassembled and all modules and parts are examined in detail. Worn out components are either repaired or replaced with the new ones. If required and feasible, model upgrading is performed on some technology modules. The remanufactured products receive a high quality assurance and are mostly delivered to customers under new product warranty contracts. In principle, remanufactured products can be sold at the same market as the original product.*

These definitions add to our understanding of the processes however the impression is still created that in order for a product to be truly remanufactured it must first be completely disassembled. While this is often the case for mechanical products that have failed due to wear out it may not be the case for products that have failed soon after manufacture or in the case of electronic products which are rarely discarded due to wear out.

The most widely used definition found in the UK was produced by Ijomah, Childe et al. (2005). It describes remanufacturing as follows.

*“Remanufacturing is the only process where used products are brought at least to Original Equipment Manufacturer (OEM) performance specification from the customer’s perspective and, at the same time, are given warranties that are equal to those of equivalent new products”*

This definition is perhaps the most useful. Ijomah, Childe et al. (2005) developed it during a production of comprehensive business process diagrams for remanufacturing processes. It is product quality rather than process based. This is important as it works for both mechanical and electronic products where complete disassembly may not improve the reliability of the product.

It is also unclear where terms such as reconditioning and rebuilding fit into the definitions detailed above. Reconditioning is a term commonly used in defence contracts in the UK often considered to be interchangeable with remanufacturing by the customer. These are key processes that need to be understood by customers as well as those carrying out the operations in order to develop less ambiguous contracts for material recovery opportunities.

Some definitions make a real distinction between remanufacturing and other material recovery opportunities in terms of the quality of the product being produced, its anticipated reliability and the warrantee offered with the product. In the opinion of the author this shows that there are two key processes running in parallel which form part of a remanufacturing process. The first is the physical strip down and rebuilding of the product

to the level required for the necessary operations, inspections and tests to be carried out. This process may be indistinguishable from a reconditioning, rebuilding or refurbishing process as all of these processes usually include complete disassembly of the item. The second is the collection of information in order to assess the reliability of a product and hence its expected life and the prediction that it will perform 'as new'.

## **1.7 Definition of Core**

According to Ferrer and Whybark (2000) a core is defined as a used product that is returned from remanufacturing. Ferrer and Whybark (2000) state this term is commonly used in the remanufacturing industry. This definition has been adopted by many researchers including Guide (2000), Jayaraman, Guide et al. (1997) and Ijomah and Childe (2007) and will be used throughout this research.

## **1.8 Remanufacturing and Sustainability**

Sarkis (2001) states that sustainable development and sustainability is most commonly defined as:

*“meeting the needs of the present generation without compromising the needs of future generations.”*

In recent years consumers have become more aware of environmental issues. Gupta (1995) reports that a series of environmental events during the 1970s and 1980s, including the Exxon Valdez oil spill and the accident at Bhopal in India, have increased environmental awareness in consumers.

More recently several other factors have increased society's interest in sustainability. The imminent peaking of world oil production as discussed by Richard and Walter (1999) and

Bentley (2002). Peak oil is the point at which global oil and gas production will start to decline leading to much higher energy prices on a global scale. Another factor is the widely, though not unanimously, accepted theory of man made climate change as described by Hill (2001). All of these factors have caused consumers and government to pay closer attention to the impact of manufacturing on the environment. This has resulted in the take-back legislation described in section 1.2 as well as other legislation, such as the Restriction of Substances Hazardous to Health, (EU (2003)), aimed at making manufacturing less harmful to the environment. In many cases this has led companies to look at a more holistic approach to product stewardship. Product designers have started to look at the impact of their products throughout their lifecycles. Erdos, Kis et al. (2001) describes how this is closely related to the cradle to grave approach where energy use, pollution and costs are analysed at all stages of product life from materials extraction to eventual product disposal.

In his book, “Remanufacturing: The ultimate form of recycling” Steinhilper (1998) states that remanufacturing can produce products of the same quality and reliability as new but using much less energy and at lower cost. Steinhilper (1998) presents examples of a sample of 5 alternators and 5 starter motors which were found to use 86% and 91% less energy to remanufacture than to produce new.

All of these factors demonstrate that there is currently increasing interest environmentally conscious manufacturing and remanufacturing. According to Defee, Esper et al. (2009) this may be to comply with EU regulations, as described in Section 1.2, to meet customer demands for environmentally responsible business practices or for economic gains related to asset recapture, as discussed in Section 1.5.

## **1.9 Summary**

Producers are facing an ever increasing amount of legislation which forces them to take responsibility for their products at end of life. Rather than acting as a burden for the producer this type of legislation has the potential for creating new profitable business models. These models include material recovery opportunities such as repairing and remanufacturing.

The remanufacturing industry is of particular interest since the products it produces are of the same quality standards as new. Remanufacturing offers a possible method for producers to process and resell their end of life or end of use products whilst guaranteeing high reliability and quality standards.

This research will study companies which already carry out remanufacturing operations. It aims to produce theory which will produce a deeper understanding of the field of remanufacturing. It aims to also produce tools, based around this theory, which could be used by companies wanting to establish remanufacturing operations as well as those already engaged in remanufacturing which have a desire to improve their processes. The following section outlines how this will be achieved in this thesis.

## **1.10 Thesis Outline**

Chapter 1 has looked at the potential for meeting the requirements, or reducing the burden, of Extended Producer Responsibility legislation such as the WEEE directive and the End of Life Vehicles Act. This legislation passes the responsibility for end of life products to those who manufactured them. A description was given for closed loop supply chains where products are returned to the market following life extension operations such as

remanufacturing. It has described how remanufacturing provides a method for producing lower cost products at the same quality as new giving benefits to the producer, customer and environment.

Chapter 2 will give details of initial meetings that were held with three companies engaged in remanufacturing in the UK. The aim of these visits was to identify the needs and problems faced by remanufacturing companies. This was done to ensure that the research would be relevant and useful to remanufacturers as well as the research community. The chapter concludes that, according to the practitioners studied, there was a need for research in the area of inspection in remanufacturing.

Chapter 3 will present a more in depth look at remanufacturing literature. It aims to show that the needs identified in Chapter 3 were not already addressed in the literature. It shows how the bulk of published research creates models with which to study remanufacturing policies under certain assumptions. The two main assumptions which limit the applicability of previous research is that both remanufacturing and manufacturing use the same facilities and that customers are indifferent to being supplied with remanufactured products in the place of new. Previous research is therefore only useful for OEM remanufacturers. An overview of literature relating to disassembly planning and sequencing was also given. It was concluded that there was little literature available that relates to inspection procedures within remanufacturing processes.

Chapter 4 will present a discussion of research methods that were used in the course of this research. It will show why case study was thought to be the most appropriate methodology for this research. Case research is shown to be particularly useful for generating theory



from practice and formalising knowledge that is held in the field by practitioners as is the case within the remanufacturing industry. The chapter will address the perceived problems of the relevance of case study research to practitioners and the difficulties of getting such research published. It concludes that in order to make the research relevant, useful and sufficiently rigorous to be published, the guidelines for case research provided by Voss, Tsikriktsis et al. (2002) would be followed.

Chapter 5 will detail the method that was used to gather evidence from case study companies that participated in the research. The aim of this stage of the research was to gain an understanding of the stages of inspection in remanufacturing processes. A discussion of the method that was used to formalise the data collected will be given.

Chapter 6 presents a generic inspection procedure, detailed the stages, aims and outcomes of inspection within remanufacturing processes. It then draws comparisons between the cases in different industries and accounts for differences in the way inspection is carried out. Chapter 6 identifies four distinct strategies for remanufacturing and presents them in a framework.

Chapter 7 describes the plan for validation of the framework for remanufacturing strategy presented in the results chapter. It describes how the research was tested against Thomas and Tymon (1982)'s 5 Necessary Properties of Relevant Research using a survey tool. It describes how this survey tool was designed to be used following an explanation of the research to the participant.

Chapter 8 will give the results of the validation survey carried out in accordance with the method discussed in Chapter 7. It finds that, although the participants all found the research accurate and interesting it was of more potential use for those new to manufacturing rather than those with well established processes.

Chapter 9 will provides a discussion of the findings of the research as a whole. The discussion includes the data that was collected at all stages during the research. A discussion of the usefulness and effectiveness of the research method will also be made.

Chapter 10 will draw conclusions from the thesis, discuss its findings and shortcomings and will present research questions that can now be addressed.

## CHAPTER 2: INITIAL CASE STUDY VISITS

Visits were made to three companies engaged in remanufacturing activities according to the definition given in Chapter 1. The purpose of these visits was to gain an idea of the problems companies engaged in remanufacturing operations feel that they face. It was also to identify other potential research opportunities and to establish contacts for future interviews. Three companies were visited for the initial case studies. The following table shows the role of each of the interviewees as well as some key characteristics of the companies and products studied.

<b>Company Name</b>	<b>Role of Interviewee/s</b>	<b>Size of Organisation</b>	<b>Amount of Remanufacturing</b>	<b>Customer</b>
CompCo	Production Manager	One facility	1,400-1,700 units per month / 100% of business	NGOs
MilCo	Managing Director, Manufacturing Systems Manager	Several UK facilities	1 batch of 768 per month / confidential % of business	MOD
JetCo	Deputy Customer Support Operations Manager, Applications Engineer	One production facility, offices internationally	30-40 units per year / 33% of business approx	Business

**Table 4 - Initial Case Visit Company Characteristics**

It can be seen from the table that all of the interviews included at least one high level manager. The companies that were studied were different size, carried out remanufacturing at different volumes and as different size segments of their overall businesses. One of the companies is OEM of the product it remanufactures, another manufactures the products it remanufactures but it is not responsible for the design and the third refurbishes products from a large number of different manufacturers.

MilCo is a military equipment manufacturer which is increasingly responsible for remanufacturing an increasing amount of equipment for the MoD. CompCo is a not for profit organisation that inspects, and repairs as necessary, end of life computer equipment before selling it to charitable organisations for reuse in developing countries. The third company, JetCo, overhauls jet engines for their customers on a regular basis. This section will detail the findings from each of these initial case studies and discusses the key differences and similarities between their processes.

## **2.1 MilCo**

MilCo is a manufacturer of many defence and energy related products. They have an annual turnover of £11M. Approximately 90% of their business is based in the defence industry with the remainder being made up of products for the energy sector. This currently comprises gas and oil industry related products but they also plan to increase their product range in the renewable energy sector.

For their activities in the defence industry their main customer is the Ministry of Defence. A typical product of MilCo's has a life cycle from conception to disposal of approximately 30 years. This commonly includes remanufacturing of the equipment by the company at regular intervals throughout its useful life.

MilCo has been involved in the remanufacturing of its own and other manufacturers' products since it was established. The majority of the products MilCo produces are currently exempt from the WEEE directive as they are used in the defence industry.

The highest volume products that are currently treated by MilCo are very different in their requirements. For the purposes of this discussion they will be referred to as product A and product B. The processing of both types of product is closely aligned with their forward manufacturing operations using both the same facilities and production staff. The MOD often makes no distinction between new and refurbished or remanufactured products. It was shown in Chapter 1 there is a clear difference between refurbished and remanufactured equipment. Refurbished items do not have the same life expectancy as properly remanufactured equipment. This causes problems for MilCo as they could be out bid by a competitor who is effectively quoting for a different job.

In the future MilCo expects to re design old products in order to enhance their performance, reliability and remanufacturability.

### *2.1.1 Product A*

MilCo offers ‘Contractor Logistics Support’ to their customers. This means that they guarantee the ongoing availability of an item for use. This requires stocks to be held to instantly replace failed units. Stocks of parts are also held for repair. Failed items are returned by the MOD when they are no longer functional. MilCo is paid for their disposal. Where possible, working parts are recovered, collected and used in the production of the replacement equipment once sufficient parts have been collected.

The company has a contract which requires it to replace failed units with ones that function correctly within a certain time period. It is also a condition of their contract that the equipment they supply must be working for a specified amount of time per year. They are also responsible for servicing the equipment at their customers’ sites. The service contract

arrangement is seen to be a win-win situation by both customer and manufacturer. One increases its overall profit from the product and the other decreases its procurement costs. It is the opinion of the Managing Director of MilCo that this is due to a 'reduction of bureaucracy on the part of the customer'.

In this particular case the company has an additional advantage when it comes to stock holding. There are 4 different types of product A but they are modular in design. It is therefore possible for MilCo to assemble to order whereas the MOD historically had to maintain stocks of each complete product.

One aspect of the contract that differs from standard service contracts is that the company cannot dictate when the products are returned to them.

Since the company provides a service rather than a product it does not matter whether the equipment that is used to provide the service is new or remanufactured. If the equipment requires additional repair due to its age or the number of times it has been reused then it would be the company that would be required to fix it. The remanufactured products are considerably less expensive to produce than the products made from new parts. The service contract is at a price fixed for a set period, in this case 5 years. Providing the service only with new products would be less profitable than utilizing a proportion of remanufactured or second life equipment as part of the contract.

Both new and remanufactured products are assembled using the same production facilities. Production of remanufactured products is more complicated when it comes to calibration.

Despite this added complexity, the production time for a remanufactured product is 4 or 5 weeks compared with a production time of 6 weeks for a completely new item.

Once received the products are visually inspected, tested to identify faulty components and finally assessed for component age. If it is deemed likely that the components will become obsolete during the next life cycle then they are replaced.

Repairs and replacements are carried out on the product based on the findings of performance and functionality tests.

### *2.1.2 Product B*

MilCo have a fixed place contract to repair these products. They are returned to MilCo on an irregular basis. The products are delivered to the factory for remanufacturing in large batches. Once the cores arrive they are inspected as a batch to verify the approximate cost of processing. They are given a category A, B or C and a renegotiated charge for processing is levied to their customer. These rates are calculated on a costs plus basis based on a labour rate covering the entire facility which includes high tech forward manufacturing.

The casing of the product is made from a valuable alloy. Remanufacturing is always viable if this casing is recovered. All other recoverable parts are removed from the assembly, cleaned, inspected, tested and reconditioned as necessary before they can be assured for reuse.

Minor variations in the products require stocks of parts to be maintained. These stocks are owned by the company but have zero book value. It is thought that the storage and finding costs of the unit are small when compared with the savings made on finding a match.

### *2.1.3 Costing*

MilCo uses a labour plus method in order to determine the cost of remanufacturing an item or recovering a part. This may be inaccurate due to the high cost equipment that is used in their new manufacturing section compared with the low tech equipment used for disassembly and cleaning operations. Goldberg (2000) describes how this is a common problem for companies engaged in remanufacturing. The low cost remanufacturing operations which often only use simple hand tools are in effect subsidising the expensive machinery used in forward production. Goldberg (2000) that use of Activity Based Costing, where product production costs are calculated based on the activities which are carried out on them, avoids these problems. Despite this they have no incentive to change this since the MOD pays them on the basis of their reported costs plus a fixed profit margin. The MOD are happy with the costing method used by MilCo. Even with this method the remanufactured items cost 40% less than new manufacture.

## **2.2 CompCo**

CompCo calls itself a not-for-profit refurbisher of used desktop computers and other computer equipment. Despite this its activities fit the definition for remanufacturing described in Chapter 1. This is because they carry out a process where used products are brought to at least OEM performance specification from the customer's perspective and, at the same time are given warranties that are equal to those of equivalent products.



CompCo processes between 1,400 and 1,700 computers per month. The vast majority of these are desktop computers however they also refurbish laptop computers. The standard process lead time is two weeks. CompCo provides the computers it processes to educational establishments and charities in various locations throughout the developing countries. At the time of writing each refurbished computer was sold for £39, this price is set to cover the processing cost. No differentiation is made between different computer specifications. At the time of writing the computers that were processed were Pentium 3 & 4 or equivalent.

A large number of computers donated are given in large batches. A charge is made by CompCo for the collection of these items. These donations are driven by the replacement of old computer systems by businesses. Therefore they are closely linked with the strength of the economy. During times when there are insufficient computers to satisfy demand, CompCo contacts businesses to encourage them to donate their old machines. When demand outstrips capacity at CompCo, computers are purchased from other not for profit computer refurbishing companies as well as from commercial computer reprocessing firms.

Computers are sorted at source as much as possible. Only high specification, working machines are accepted. Computers that are found to not work or to be the wrong specification are recycled with the cost, plus a charge, charged to the equipment donor. This is done in order to stop people using the company as a means for disposing of waste and to ensure the quality of the used computers the company receives.

CompCo believes that the computers it supplies should have a working life of 3 to 5 years. Their computers have been found to perform well and meet this requirement. The

computers also appear to outperform new equipment. CompCo believes that this is due to the good quality brands of machines that they deal with and the proven reliability of the machines after years of use.

CompCo refurbishes working equipment and so is not dealing with waste. For this reason it is not licensed under the waste act and so can freely export computers to wherever they are needed. Despite this it was thought that the WEEE directive would lead to a large increase in donations to CompCo, mostly from companies wanting to reduce the amount of WEEE they produced. As of the time of this interview, in May 2006, these had not yet materialised. It was thought that this was due to the fact that the legislation was not in force in the UK at the time of the interview. It was still thought to be a possibility that computer manufacturers would contact companies like CompCo to reduce their WEEE burden.

### *2.2.1 The CompCo Remanufacturing Process*

Computers arrive at the London warehouse in an unknown condition. Information on the condition of the computers is sometimes given by the donor but it often turns out to be inaccurate. For this reason all of the decision making about the suitability of a machine for refurbishing is made on the basis of a visual inspection, the model of the computer and an estimation of its age. If it is decided that a computer is not suitable for remanufacturing it is sent for materials recycling. Occasionally these computers can be cannibalised if there is a need for the parts. There is an organisation in the USA, known to CompCo who is currently developing a data base of parts that are contained within different computer models to ease this decision making process.

During the next stage of the process, the data wiping, the machine specifications are found using diagnostic software. Based on this it is decided whether the computer is suitable for reuse as it is, whether it requires upgrading or whether it cannot be used at all.

Computers and their original peripherals, such as keyboards and mice, are kept together while they pass through the process. This is so that colour matches can be maintained and working computers are kept together as much as possible. There is no tracking system used to trace the progress of desktop computers through the process. CompCo believes that use of such a system would cause a large amount of additional work but would have few tangible benefits.

There are no standard part replacements made but computers are cleaned and brought back to a working condition before they are shipped. Experience has found that the most likely part to fail during second life use is the Power Supply Unit (PSU). This is due to the fluctuating mains power supply in many of the locations where the computers spend their second lives.

### *2.2.2 Costing*

The processing cost at CompCo is simply found by dividing the total cost of operating by the number of computers processed in that period. Since they only produce one type of product and sell it at a fixed cost this is an appropriate costing method. Goldberg (2000) explains that more simple costing methods are preferable to Activity Based Costing in the cases of simple products.

## **2.3 JetCo**

JetCo is a manufacturer of gas turbine generator sets and complex components based in the UK.

The generator sets they package give cogeneration of electricity and heat and are 80-85% efficient. In some models the heat is used to raise steam which can be injected back into the engine to enhance its power. Their current range generates between 2.5 and 6 MW of power and only require a process described as “overhaul” after over 30,000 service hours. This is in contrast to diesel generators which often only run for a total of 16,000 hours before major overhaul work is required. The tasks carried out during the overhaul process fall within the definition of remanufacturing provided in Chapter 1. This is because they carry out a process where used products are brought to at least OEM performance specification from the customer’s perspective and, at the same time are given warranties that are equal to those of equivalent products. Once processed, they are expected to be at least as reliable as new equipment.

JetCo have sold 230 generator sets based on this engine in the past 20 years and hold maintenance contracts for the vast majority. Maintenance contracts are sold with most units and last for 5 or more years. It is thought that more money is made through after sales services, such as through service contracts, than in the sale of new units. The contracts stipulate a guaranteed system availability, typically 95 to 98%. The units are linked to the JetCo head office via a SCADA (Supervisory Control And Data Acquisition) system. Due to this system the reason for failure of a system is often known before service engineers arrive at the site where the system is located.

### *2.3.1 Engine Remanufacturing*

When engines reach a running time of over 30,000 hours they are returned to JetCo's facilities for remanufacturing. It is only the engine that is sent for remanufacturing and not the remainder of the generator set. This is due to it experiencing the most extreme conditions and having the highest value of all the components.

During an overhaul, engines are disassembled and worn parts are removed and replaced with new ones. Parts that are known to wear and are exposed to the most extreme conditions are given the most detailed inspection and are inspected first. Once the engine is reassembled it is put through the same test procedure as a new engine. It is then transported back to its original location and is swapped with the substitute engine.

### *2.3.2 Costing*

A continuous process is carried out to determine the profitability of each maintenance contract over its life. Processing cost is calculated based on the number of hours worked on each unit.

## **2.4 Initial Case Studies Discussion**

A description of the processes of three very different companies has been made. Each of the three companies has a different name for the processes they carry out however they have certain things in common. The most important commonality is that they take used equipment, pass it through a process and once processed expect it to be reliable for a full second life. Inspection is a key part of each process although its exact role differs between the cases. Product B produced by MilCo is expected to last as long as a new unit. CompCo

state that the performance of their reprocessed computers is at least as long as for a new unit.

Referring back to the definition of remanufacturing provided by Ijomah, Childe et al. (2005) as *a process of bringing used products to “like new” functional state with warranty to match* it appeared that all of the companies studied have processes that could be described as remanufacturing.

The following diagram summaries some of the key differences between the three cases that were studied:

	<b>Amount of Disassembly</b>	<b>Amount of Cores Used</b>	<b>Product Returned to</b>	<b>Core ownership</b>	<b>Core Use Decision Made Based on</b>	<b>Part Reuse Decision</b>
<b>CompCo</b>	As required to facilitate part replacement.	Most	New customer	Remanufacturer	Age, Specification, Visual Damage, Work Required	Demand for spares
<b>MilCo</b>	Total	Almost all	Existing customer	Remanufacturer	Visual damage to specific part, Work Required (customers decision), order lead time	Wear/Damage, age, spec, order lead time
<b>JetCo</b>	Total	All	Equipment Owner	Customer	All processed	Wear/Damage

**Table 5 - Initial Case Comparison Table**

It can be seen from Table 5 that there were many differences between the three cases that were studied. Cores that were found to not have sufficient value for CompCo to process were recycled at the cost of the supplier of the equipment. In contrast to this the other cases

had to process what had been supplied. In the case of JetCo, the original engine must be returned whereas in the case of MilCo an effort is made to reuse as much as possible of the returned equipment in order to remain competitive.

The tendency for a company to discard unsuitable cores in some cases appears to be driven by process lead time, ownership of core, the amount of work required on a core and how damaged it is. Though indirectly used in all of the cases, through amount of work decisions etc, cost was not observed as being in use as a decision making factor during the remanufacturing processes themselves.

The 'bang-bang' approach to operationalising an end-of-life strategy for a product described by Richter (1997), where all products are processed using the same process regardless of condition, appears to be in use in two of the three companies. All of the units they receive are processed with limited consideration of the costs involved. For JetCo this is essential since it must return the item to its owner once it has been remanufactured. For MilCo it is less essential and may well prove to be the wrong strategy. This will only become clear with a more in depth analysis of their processes as well as other remanufacturing organisations.

## **2.5 Research Aims**

Remanufacturing has been identified as an important process which can be used by companies to produce high quality and environmentally efficient products whilst reducing the burden of producer responsibility laws.

It has been shown in Table 5 that the three cases that were studied showed that remanufacturing processes can be run in very different ways. One thing that is not clear is if these differences are specific to each case or if they are attributable to certain, perhaps unknown, remanufacturing strategies. It can be seen from Table 5 that inspection is one area in which the cases show large differences. For example core inspection is carried out using different methods and decision making processes, part inspection is not carried out at all by CompCo whereas it is a key part of the process for MilCo and JetCo.

This research seeks to understand if these differences in processes are due to different remanufacturing strategies that are being operated. It will attempt to identify different remanufacturing strategies that are in use and find the underlying reasons for the use of each. The following chapter will review existing theory in the area of remanufacturing and inspection in an effort to explain what has been observed in the initial case studies that have been described in this chapter.



## **CHAPTER 3: LIMITATIONS OF EXISTING REMANUFACTURING AND INSPECTION LITERATURE**

This chapter aims to provide a review of existing operations management literature in the field of remanufacturing and inspection.

This chapter aims to demonstrate that there is a need for the development of new theory in the area of inspection within remanufacturing processes. Literature was identified and located using online databases of abstracts. Following this, references of interest within the initial papers were located and read. Recommendations for further literature from colleagues at remanufacturing seminars were also investigated.

### **3.1 Inspection and Total Quality Management**

There has been a large amount of literature produced looking at the purpose of inspection in traditional forward manufacturing.

It has been reported by Dale (1999) that inspection has been defined in ISO8482 as:

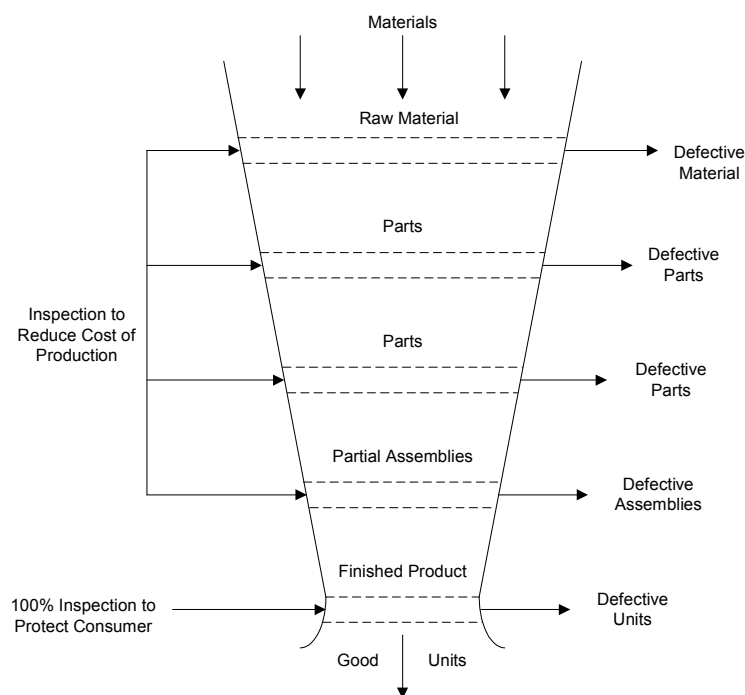
*“Activity such as measuring, examining, testing or gauging one or more characteristic of an entity and comparing the results with specified requirements in order to establish whether conformity is achieved for each characteristic.”*

Inspection and Total Quality Management (TQM) are inextricably linked. Crosby (1980) states that Inspection: The base of every quality program is data collected through physical

and mechanical inspection. Dale (1999) states that in the early days of TQM, inspection was thought of as being the only way to insure quality.

### 3.1.1 Types of Inspection within a Manufacturing Process

Shewhart (1931), who is described in the book as “*the father of modern quality control*”, presents a case of a telephone manufacturer. A diagram adapted from this case is shown in the following figure:



**Figure 2 - An Economic Production Scheme adapted from Shewhart (1931)**

He explains that inspection of the materials, parts and components from which the resulting telephone is manufactured is carried out in order to reduce the cost of production whereas the final (100%) inspection of the finished products is carried out in order to protect the consumer against the risk of buying a faulty product.

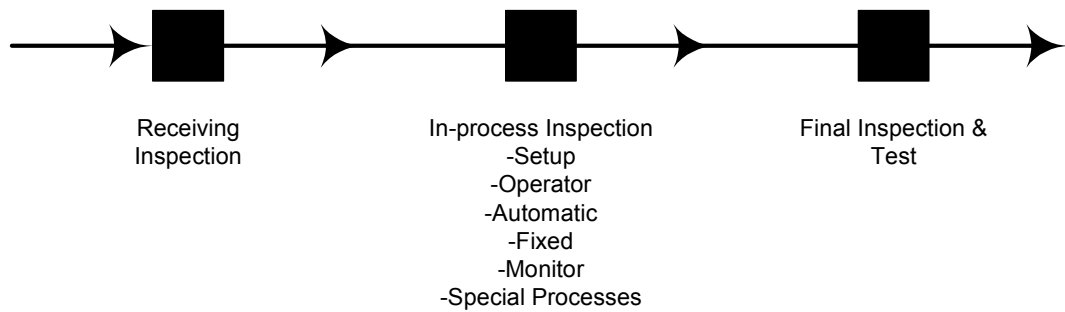
In a paper looking at the problems with sustaining total quality management in manufacturing firms Dale, Boaden et al. (1997) stated that

*“...only in a minority of cases did people hold the view that final inspection would take the responsibility for product quality.”*

This is in contrast to the theory given by Shewhart (1931) who stated that only the final stage of inspection was there to protect the customer. Although it may have been the intention of the process designer that all defects are removed in the final inspection stage of their process this may not be the case in reality. Winchell (1996) explains that even with 100% inspection there is still a possibility of defects being passed along the system. This is described as being due to human frailty.

Developments such as the Poka-yoke system developed by Shingo (1986) embody the concept that no fault or defect should be passed along the production process, not only to reduce cost but also to avoid the risk of those defects reaching the consumer. This is in contrast to Shewhart (1931)'s theory that in process inspection is only to reduce processing cost.

The following figure shows the typical types of inspection within a manufacturing process:



**Figure 3 - Typical types of inspection in the process adapted from Winchell (1996)**

It can be seen in Figure 3 that inspection is typically carried out at three more distinct locations within a manufacturing process. On material before it is processed, during the process itself and on the final product before it is released. Dale (1999) reports that ISO9000 requires inspection to be carried out on goods received, in-process and for the final product as is shown in Figure 3.

Receiving inspection is carried out to ensure that feedstock materials are of the required quality. Winchell (1996) describes that this is sometimes no longer necessary if the quality control processes of the companies supplying the materials can be relied on. In process inspection is carried out so that faults can be rectified as soon as they are noticed. Winchell (1996) goes on to state that the purpose of final product inspection is to assess if the requirements of the customer have been met.

### *3.1.2 Sampling, 100% or Zero Inspection*

Sampling inspection is a common method of ensuring some level of defects within set statistical confidence limits. Random samples of product are collected and tested. On the basis of these tests a batch is either accepted or rejected. Deming (2000) reports that such

methods have been popular in the past but do not give the whole picture. Shingo (1986) states that in using sampling inspection it is assumed that a certain number of defects are unavoidable and by extension that disappointing a certain number of customers is also unavoidable. Shingo (1986) quotes a case of the managing director of Matsushita Electric's who didn't want a single product made in their factory to be defective. Shingo (1986) states that sampling inspection can reduce defects but cannot eliminate them. It is therefore not appropriate for Matsushita Electric and “ *is not necessarily appropriate from the point of view of zero-defects-orientated quality assurance.*”

Dale (1999) explains that the ideal situation would be to inspect the entire lot and thus make absolutely certain of quality. He goes on to comment that this is often impractical due to the high cost of the testing procedures involved. Shingo (1986) provides low cost inspection techniques that can make the cost of inspection very low indeed.

Shewhart (1931) takes a different stance and states that if we can be assured that something we use is produced under controlled conditions, we do not feel the need for inspecting it as much as we would if we did not have this assurance. He explains that the quality of the finished product is a direct result of the quality of raw materials, piece-parts, and the assembling process itself.

The concept of “Self inspection” is discussed Shingo (1986). This is a way of shortening the inspection feedback loop meaning that process faults are rectified sooner and mistakes or errors have less time to become defective parts or products. One common criticism of Self Inspection identified by Shingo (1986) is that operators might compromise on quality letting low quality parts they have produced pass their inspection. In order to address this

Shingo (1986) proposes that inspection could be carried out by the operator who receives the materials before he or she starts to process it. This is described as the successive check system. It is stated by Dale, Y.-Wu et al. (2001) and Martinez-Lorente, Dewhurst et al. (1998) that a key part of TQM is that “*self inspection must be undertaken using clear work instructions*”.

Deming (2000) gives formulae that can be used to calculate the amount of inspection for a given lot. It uses the cost of inspection and the cost of allowing a defective part to enter the system to find the optimum method. This is zero inspection where the cost of inspection is relatively high and the cost of a defect entering the system is relatively low or 100% inspection when the cost of inspection is low and the cost of a defect entering the system is high. For cases with moderate cost of inspection and moderate cost of a defect entering the system Deming (2000) explains that sampling inspection is suitable.

### *3.1.3 Inspection Summary*

Formally thought of as the only way to ensure quality, inspection is of great interest in forward manufacturing. It is used to lower processing cost, the cost of processing defects, and to protect the customer against receiving a defective product. There are circumstances in which sampling or zero inspection can be used but it is claimed that only though 100% inspection can zero defects be ensured.

Inspection can be carried out through visual or mechanical checks and in some cases specialist tests. Historically it has been carried out by separate quality control operators. Things are now moving towards in line process inspection and self inspection where 100% of the products are inspected.

## **3.2 Remanufacturing Literature**

There is currently a large amount of interest in return-to-market operations. This has led to a significant body of literature that addresses problems that might occur in remanufacturing operations. This section will give a review of the operations management literature based in the field of remanufacturing.

### *3.2.1 Decision Models*

A large amount of research that has been carried out in the area of operations management for remanufacturing is based around quantitative decision models. This section will look at decision models that have been developed by researchers. It will group them firstly by what they are trying to achieve and secondly by the assumptions that were made in order to develop the models. Finally a discussion will be made about the relevance of these assumptions to remanufacturing companies. The aim of this is to establish which types of remanufacturer have the most and least help from the research community.

### *3.2.2 Manufacturing Process Control*

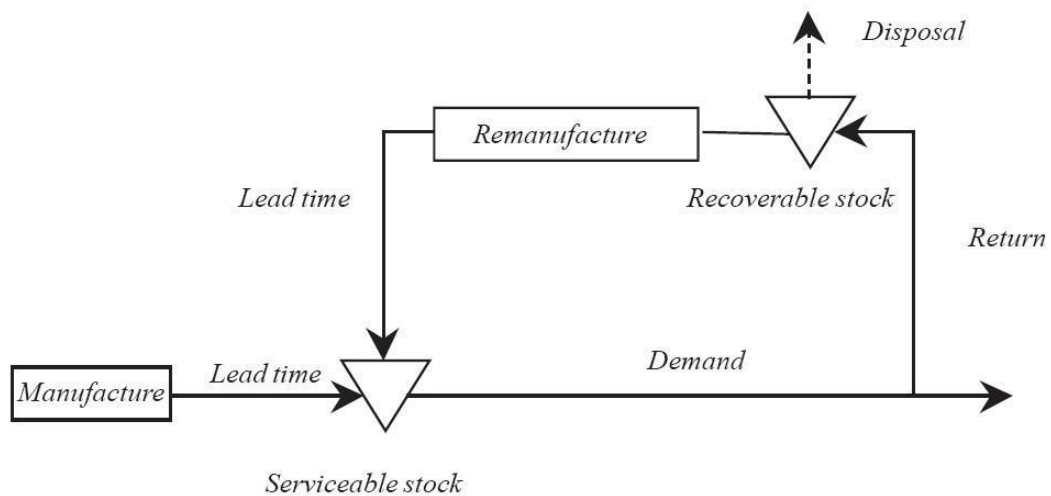
It is stated by Guide, Jayaraman et al. (1999) that there are six major factors that significantly complicate remanufacturing process control.

1. probabilistic material recovery rates of the parts from the inducted cores
2. unknown condition of the recovered parts until inspected
3. the part matching problem,
4. the need to disassemble products,
5. the problem of imperfect correlation between supply of cores and demand for remanufactured units
6. the uncertainties in the quantity and timing of returned products

In forward manufacturing the quality and volume of raw materials can be ordered as required. Guide, Jayaraman et al. (1999) state that this is not the case in remanufacturing. Remanufacturers must be able to forecast the return of cores as well as the demand for their finished products. According to Guide, Jayaraman et al. (1999) the variable quality of cores means that materials requirement planning is also more complex. Researchers including Souza and Ketzenberg (2002), van-der-Laan (2003) and Kiesmuller (2003), as well as many others detailed in this section, have attempted to address these problems modifying existing manufacturing models accordingly.

### 3.2.3 Hybrid Manufacturing Model

One major assumption which is used in a large number of research papers is that the remanufacturer is operating a hybrid manufacturing process. In this process, new and remanufactured products are produced using the same production line. Usually it is assumed that demand for products can be met using either remanufactured products or new units since no distinction has been made between them. The following figure shows the diagram, taken from Tang and Grubbström (2005) which is typically used to demonstrate how a hybrid system operates.



**Figure 4 - Hybrid Remanufacturing System taken from Tang and Grubbström (2005)**



It is unclear how common this method of operating is in industry. It may require the remanufacturer to also be the OEM of the product. It may also rely on customers making no distinction between new and remanufactured products. On the other hand it allows for some interesting models to be developed.

The table that follows gives a brief overview of some of the subjects that have been studied using models based on hybrid remanufacturing systems.

Author	Study of	Key Assumptions
Yongjian, Jian et al. (2006)	Reman/New Production Mix	Multiple product types. Substitutable demand.
Tang and Naim (2004)	Information transparency	Push type system
Tang and Grubbström (2005)	Ordering policy	Constant demand. Stochastic lead times.
Souza and Ketzenberg (2002)	Reman/New Production Mix	Shared resource
Rubio and Corominas (2008)	Reman/New Production Mix	Lean system
van-der-Laan and Teunter (2006)	Reman/New Production Mix	Stochastic returns. Push and pull systems
van-der-Laan (2003)	EOQ calculations for remanufactured products	NPV and AC inventory models
Li, Mohamed et al. (2006)	Kanban policy	New manufacture is controlled by APIOBPCS system
Grubbström and Tang (2006)	Production decisions	Cobb-Douglas properties of production and decreasing marginal returns to scale.
Kiesmuller (2003)	Stocking points	Stochastic, substitutable demand (different lead times)
Kiesmuller (2003)	Stocking points	As above but includes items in the hands of consumers
Li, Chen et al. (2007)	Batch sizing	Substitutable demand.
Bayindir, Erkip et al. (2007)	Reman/New Production Mix	Cores are widely available
Rainer, Stefan et al. (2002)	Reman/New Production Mix + Core disposal	Dynamic demands and returns.
Imre (2003)	Inventory policy	Two store system
Ruud, Bayindir et al. (2006)	Lot sizing	Different sizing heuristics used
Jian, Boaz et al. (2005)	Production planning	Substitutable demand.
Inderfurth (2004)	Reman/New Production Mix	Substitutable demand.
Zhou and Disney (2006)	Bullwhip effect	Substitutable demand.

**Table 6 - Hybrid Remanufacturing Literature**

It can be seen from Table 6 that in most cases it is assumed that the items are produced using the same facilities. This is not just a convenient assumption for mathematical optimisation, Ketzenberg, Souza et al. (2003) report that these are real scenarios and state examples such as Kodak and Xerox. Hybrid systems are interesting cases to study however is not the case that the whole of the remanufacturing industry operates in this way. Many 3<sup>rd</sup> party or independent remanufacturers and even those that are the OEMs of the products they remanufacture rarely receive the products back while they are in forward production. For these reasons many remanufacturing operations use different facilities or equipment for remanufacturing than they do for new product manufacture.

The other main assumption as shown in Table 6 is that customers are indifferent to receiving remanufactured or newly manufactured items. It is true that remanufactured items can be indistinguishable from new, however laws in many places would mean that all equipment would have to be properly labelled as remanufactured. There are some products for which this is not an issue, such as Kodak's single use cameras, however it is possible that consumers may be resistant to pay full price for something that is not technically new.

### 3.2.4 Non Hybrid Systems

There is another body of literature in the area of remanufacturing which does not make the hybrid system assumption. The following table outlines this literature.

Area	Author	Study of
Scheduling and Batch Sizing	Guide, Srivastava et al. (1997)	Product complexity and scheduling
	Guide, Srivastava et al. (1997)	New capacity planning techniques
	Guide, Gilvan et al. (2005)	Priority rules in two product facility
Inventory Management	Nakashima, Arimitsu et al. (2002)	Optimum core recovery and discard rates in a two store system.
	Nakashima, Arimitsu et al. (2004)	Optimum core recovery and discard rates in a two store system including cores in field.
	Bayindir, Erkip et al. (2003)	Inventory holding cost
Deteriorating Cores	Barketau, Cheng et al. (2008)	Batch scheduling
	Voutsinas and Pappis (2002)	Scheduling of PC Remanufacture
	Chun-Jen and Hui-Ming (2008)	Scheduling of MP3 Power Supply Remanufacture
Disassembly Planning	McGovern and Gupta (2006)	Disassembly line balancing using Ant colony optimisation
	McGovern and Gupta (2007)	Disassembly line balancing using Genetic Algorithm
	Inderfurth and Langella (2006)	Disassembly to order strategies

**Table 7 - Non Hybrid Remanufacturing Literature**

Table 7 shows that there is a fairly significant body of literature that does not make the hybrid system assumption. It covers familiar areas in operations management such as scheduling, inventory management and batch sizing. It addresses some of the added complications of remanufacturing as discussed in section 3.2.2. Another interesting area that is covered in the literature is the provision of models for scheduling with cores that are deteriorating in value or condition while in storage.

This literature does not make all of the assumptions detailed in the previous section. However it can, on the whole, only be used by practitioners with established procedures in

order for them to optimise their processes. It is unclear how well these models work as none of them have provided implementation or validation studies.

#### *3.2.5 Disassembly Sequencing*

Disassembly sequencing has provided a fertile area for researchers as it is relevant not only for remanufacturers but indeed any other industry which must disassemble products. This includes some recycling companies as well as repair shops and product upgrade facilities. Disassembling products using an optimum sequence to the correct level is an area in which many models have been created. Lambert and Gupta (2005) provide a comprehensive review of methods which have been produced.

### **3.3 Inspection in Remanufacturing Operations**

Inspection of cores is carried out so that only cores that are suitable for returning to market are processed. Guide, Jayaraman et al. (1999) and Georgiadis and Vlachos (2004) agree that a vital stage of the remanufacturing, repair or resale of a product is the inspection stage. Indeed it is referred to by Krikke, Bloemhof-Ruwaard et al. (2003) and Guide, Muyldermans et al. (2005) as one of the five key activities of all reverse supply chains as described in Section 1.5.1. It is considered to be a mandatory process in the reverse supply chain along with product acquisition and cleaning. Blackburn, Guide Jr. et al. (2004) explain that the purpose of this stage is to assess the condition of the core and to make the most profitable decision for reuse. This must be done in order to identify the type of product, its state of wear and the estimated profit from re-processing it. Despite the clear importance of the inspection process there has been little research carried out into the current practices of industry. This section will discuss the small amount of relevant literature that there is available.

### *3.3.1 Methods Currently Employed*

Steinhilper (1998) describes how inspection is sometimes carried out on parts in the automotive industry using magnifying glasses, microscopes, high resolution cameras with electronic image processing as well as measuring devices. A returned item is looked at and a decision is made to determine if it is usable, unusable or usable after some further work. A survey of Automotive Parts remanufacturers was carried out by Hammond, Amezcua et al. (1998). It was found that the “Inspectors Knowledge” was the thing that made inspection most difficult for 29% of the respondents. In none of the other questions was the skill of the employee rated so highly. This indicates that inspection requires tacit knowledge and experience and currently, running a successful inspection process depends largely on the skills and knowledge of the person carrying out the inspections.

In an attempt to standardise their inspection processes Xerox developed mechanical techniques to test its parts. It then uses these to determine the predicted length of life remaining in the part and hence whether it should be reused or not. Goldberg (2000) reports one such technique. Vibration energy measurements are made for induction motors used in its photocopiers to determine if they can be reliably reused. According to Maslennikova (2000) other photocopier manufacturers have copied these techniques but it is not apparent from the literature how common they are within the remanufacturing industry.

### *3.3.2 Future Inspection Methods*

Goldberg (2000) reports that Bosch has carried out tests with micro sensors to record data during the life of its power tool motors. The idea is that once the tools are returned to them at End of Life they will be connected to a data reader which will easily decide if the motors can be reused. Nagel and Meyer (1999) reports that similar technology is being developed,

as part of the Care Vision 2000 initiative, to produce what they call a 'Green Port'. In addition to data detailing the use of the product it will contain information about the materials contained in the product and the location of hazardous substances and disassembly information.

### *3.3.3 Summary of Inspection Procedures*

Technology which has the potential to reduce over dependence on tacit knowledge and to reduce variability in inspection is being gradually produced which may lead to some interesting developments in the future. Little research has been carried out to determine the business processes that are involved in this key stage of EOL product processing. This technology may be useful for certain products however there may be others for which manual inspection will remain the most cost effective method. Ketzenberg, Souza et al. (2003) report that there were an estimated 73,000 firms in the USA engaged in remanufacturing activities in 1998. Many of these are 3<sup>rd</sup> party remanufacturers, remanufacturers that do not have the support of the original equipment manufacturer, and it seems unlikely that green ports will provide them with a solution to the inspection problem. All remanufacturing, and other firms involved in returning products to market, are currently carrying out these inspection procedures using a multitude of methods. A deeper understanding should be developed of these processes so that they can be improved.

Once a product reuse strategy has been selected and put into operation then it is likely to be the case that not all of individual items returned should be processed in that way. One of the commonly agreed complexities of remanufacturing highlighted by Ferrer and Whybark (2000) as well as Guide, Jayaraman et al. (1999), is the varying condition of products when they are returned after the use phase. Ferrer and Whybark (2000) discuss how identifying

the type and condition of a core through inspection is a key part of the remanufacturing process. They go on to state that the processing of scores that are too costly to remanufacture or to dispose of cores that would be profitable to remanufacture can lead to a loss of profit.

A significant amount of research has been directed towards technologies that are capable of collecting information about a product both when it is manufactured and when it is in use as well as storing information to aid the environmentally efficient disposal of the item at its end of life. This sort of technology would greatly reduce the amount of inspection and testing required before a decision is made about an item however there is no mention of how this technology will be integrated into existing remanufacturing operations.

Such technologies offer a great amount of information about end of life products and will be useful to manufacturers who install them in their products. However it is thought these technologies are likely to be protected by patents and only be of use to OEM remanufacturers. It seems very unlikely indeed that a system will be designed by OEMs from which independent remanufacturers will benefit.

The survey of automotive remanufactures carried out by Hammond, Amezcuita et al. (1998) showed signs that the industry is heavily reliant on the skills and tacit knowledge of its operatives in order to carry out inspection operations. Reliance on such tacit knowledge makes it difficult to remove operator bias from the process. It is possible at present that a job that is seen to be unprofitable may be discarded even when it could have made a profit. This is due to the human frailty discussed by Winchell (1996).

The benefits that can be realised by product redesign and the incorporation of green ports as described by Goldberg (2000) can only be realised if the companies carrying out remanufacturing are either the original equipment manufacturer or are working in cooperation with them. Sadly according to a survey by Hammond, Amezquita et al. (1998) showed that 18% of the automotive remanufacturers who took part in his survey never talk to the OEMs of the products they remanufacture and only 23% have contact on a daily basis.

### **3.4 Literature Discussion**

There is an increasing body of literature that is aimed at helping improvements to be made to the design of products for a certain end of life option during product development. These include such developments as Design for Dissassembly, Design for Remanufacturing and including technologies such as green ports. This will prove to be extremely useful once these products reach their end of life.

These developments are only of use to remanufacturers processing equipment working in close collaboration with the original equipment manufacturers and whose benefits will only truly be known when the products being designed now begin to reach their end of lives.

The inspection and core/part/product replacement decision process appears to be an area of great importance to the efficiency of remanufacturing processes into which little work has been carried out. A survey of automotive remanufacturers carried out by Hammond, Amezquita et al. (1998) confirms that this is an area with which remanufacturers have issues. Inspection is currently heavily reliant on the skills and knowledge of the inspectors



themselves. Some companies have started to incorporate part testing and analysis into their processes but it is unclear how widespread this practice is.

New technology is likely to make inspection more easy however it is unclear exactly how data from technology such as the green ports will be incorporated into existing remanufacturing inspection procedures.

The literature from inspection in forward manufacturing has shown that 100% inspection is preferable to sampling inspection when possible. It has shown that this can be achieved in some cases using low cost visual checks and self inspection. In a labour intensive process such as remanufacturing this may be a very useful technique.

Very little has been found in the literature about how inspection is carried out within remanufacturing processes. Steinhilper (1998) gives a description of a typical process however it is unclear if it is done in the same way in all industries, if there are techniques that are more suited to some products than others or if there is scope for increasing the efficiency of such operations.

Guide (2000) identifies with this problem. He states that there is a need for more case studies to be carried in remanufacturing so that best practice can be identified and shared. This is as much the case in the inspection process as it is with remanufacturing as a whole. The following section will outline the research questions that will be asked to address this deficiency.

### 3.5 Conclusions and Research Questions

The literature review as shown that only a limited amount of research exists that is of use to remanufacturers that are not in partnership with OEMs. Few case studies exist of remanufacturing processes and it is not apparent from the literature if the differences observed in the initial case studies described in Chapter 2: are part of a pattern or signify the operation of different remanufacturing strategies.

In their survey, when talking about OEM cooperation Hammond, Amezcuita et al. (1998) conclude that *“the only way we can help increase the remanufacturability of those products is by improving the remanufacturing processes.”* Guide (2000) for more case studies to be carried in remanufacturing so that best practice can be identified and shared. This research uses case studies to identify and formalise the current methods used in remanufacturing processes in different industries. The research investigates companies with good relationships with the OEMs of the products they manufacture as well as those with limited communication.

Based on the findings of these initial case visits discussed in Chapter 2: and the review of theory that has been outlined in this chapter, this research will aim to find answers to the following questions:

- 1) It appears that there are differences in the inspection processes carried out by the three cases described in Chapter 2: Are all processes different or are these differences part of a pattern of different strategies?
- 2) Assuming these differences are due to different strategies, what are the company or product characteristics which affect the choice of remanufacturing strategy?
- 3) What knowledge and skills are required for the effective management of a remanufacturing process using each of these strategies?

## CHAPTER 4: RESEARCH METHODOLOGY

This chapter will discuss how the research was carried out in order to make it relevant and interesting to both operations managers and academics while being sufficiently rigorous to ensure a valid contribution to theory.

### 4.1 Introduction

In order to ensure that the research is relevant to those who will use it, it was thought that field research methods such as case study, survey and action research should be used in order to understand problems in their industrial context.

The following table shows the number of articles published in operations management journals since 1995 on the subject of remanufacturing.

Journal	Source	Papers Published Since 1995		
		All	Remanufacturing	as %
Journal of Operations Management	Science Direct	811	16	1.97%
International Journal of Operations & Production Management	Emerald Insight	1075	9	0.84%
Production and Operations Management	Wiley Interscience	568	18	3.17%
Production Planning & Control	Taylor & Francis	1221	6	0.49%

**Table 8 - Remanufacturing Articles Published 1995 till Present**

Table 8 demonstrates that, at the time of writing, research in Operations Management of remanufacturing operations was a relatively immature area. The earliest article that was found to mention remanufacturing during this search was one written by Gupta (1995) which comments on the need for products to be designed with remanufacturing in mind rather than just materials recycling.

Despite the apparent immaturity of the research area, it was thought that there was a huge amount of technical expertise within companies that in some cases had been carrying out these activities profitably for over two decades. This includes two of the three initial case studies described in Chapter 2:

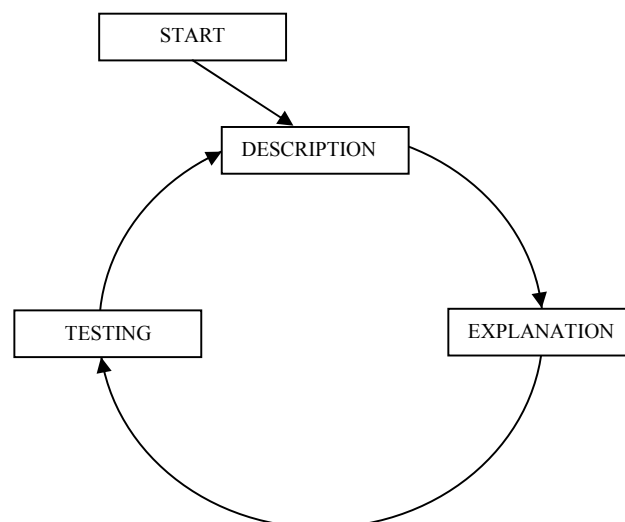
Meredith, Raturi et al. (1989) discuss three reasons why operations managers have had little interest in operational research in the past. They state that research has;

- narrow instead of broad scope,
- technique instead of knowledge orientation and
- abstract instead of reality perspective.

It was thought that field based research methods such as case study, would solve many of these problems. A broad scope could be covered with no strict boundaries set out at the beginning of the research and the theory that was ultimately developed was more likely to be useful to operations managers as it was developed with their close involvement and cooperation. As suggested by Meredith (1998).

## 4.2 Maturity of the Research Area

The following diagram shows the well known research cycle proposed by Meredith, Raturi et al. (1989).



**Figure 5 - Meredith's Research Cycle, Meredith, Raturi et al. (1989)**

Meredith's Research Cycle shows that all emerging research fields start with a descriptive phase where the existence of phenomena is established. The next stage of the cycle is to attempt to explain the causes of these phenomena. The third stage of the cycle is to test the explanation that has been developed which can lead back to a new descriptive phase.

In the introduction to this chapter it was commented that research in the area of remanufacturing was immature. Due to this immaturity it would make sense that a large amount of research would be carried out in the description phase of Meredith's research cycle. This was not always found to be the case in this field. Even when research started based on real problems, unrealistic assumptions were often made and solutions rarely implemented. In contrast to this the main aim of research in the descriptive phase is to formalise knowledge that already exists and to develop theory from it.

Case study has been defined by Hussey and Hussey (1997) as being a methodology which focuses on understanding the dynamics present within a single setting. They go on to comment that it is often used in the exploratory stages of research such as is the aim of this research project.

Benbasat, Goldstein et al. (1987) explain that case study research is a viable and very useful research methodology. The reasons they give are as follows;

- The researcher can study information systems in a natural setting, learn about the state of the art, and generate theories from practice.
- The case method allows the researcher to answer "how" and "why" questions, that is, to understand the nature and complexity of the processes taking place.

- A case approach is an appropriate way to research an area in which few previous studies have been carried out.

Benbasat, Goldstein et al. (1987) wrote their paper in the context of information systems research however it was thought that it is just a relevant in this field of research. Indeed their work on case research methodology has been referred to by prominent Operations Management researchers such as Meredith (1998).

It has been discussed that case research can be a useful technique for carrying out research in the descriptive phase of Meredith's research cycle (shown in Figure 5), where there is a large amount of expertise in the field which needs to be captured and formalised. It has also been discussed that case research is thought to be particularly accessible to non researchers at a time when relevance and accessibility was becoming a key issue in the field of operations management. In light of these points it is surprising that case study based research does not appear more the most popular Operations Management journals.

Meredith (1998) proposed that this was due to a lack of understanding of the methodology. He quoted a case where a researcher's paper was rejected by referees on the basis that his sample size was too small to draw statistical conclusions. In fact he had carried out case research with the entire population of relevant companies. Voss, Tsikriktsis et al. (2002) admitted that, at best, only a limited amount of statistical analysis could be carried out on case based research. They also stated that despite this it was one of the most powerful research methods applicable to operations management research.

McCutcheon and Meredith (1993) state that case studies were an effective means for enhancing our knowledge about how operations systems work, however some members of the research community considered it to be a weak form of research which lacked rigour and objectivity. A paper by Flyvbjerg (2006) stated that this was likely to be due to the following five misconceptions of case study research:

- General, theoretical (context-independent) knowledge is more valuable than concrete, practical (context-dependent) knowledge.
- One cannot generalize on the basis of an individual case; therefore, the case study cannot contribute to scientific development.
- The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypothesis testing and theory building.
- The case study contains a bias toward verification, that is, a tendency to confirm the researcher's preconceived notions.
- It is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.

He also commented that some of the researchers who were originally most critical about case research started to use it regularly as their preferred method. He stated the example of Campbell and Stanley (1966) who once stated, of case studies, that "Such studies have such a total absence of control as to be of almost no scientific value." His later work gave evidence of something of a U turn in his thinking. Later Campbell (1975) published a paper entitled "Degrees of Freedom and the Case Study"



As a response to this scepticism several researchers including McCutcheon and Meredith (1993), Meredith (1998) and Voss, Tsikriktsis et al. (2002) have provided frameworks for ensuring rigour in case based research. These frameworks were followed in the course of this research to ensure that it was carried out in a sufficiently rigorous manner to be sufficiently reliable and useful to Operations Managers.

The following section details how the research was carried out in such a way to ensure it was sufficiently rigorous.

### **4.3 Ensuring Rigour in the Research**

A framework proposed by Voss, Tsikriktsis et al. (2002) was followed in order to ensure the research was sufficiently rigorous. This section details actions that were taken under each of the headings in the framework. These are as follows;

- (1) When to use case research.
- (2) Developing the research framework, constructs and questions.
- (3) Choosing cases.
- (4) Developing research instruments and protocols.
- (5) Conducting the field research.
- (6) Data documentation and coding.
- (7) Data analysis, hypothesis development and testing.

#### *4.3.1 When to use case research*

Due to the descriptive nature of this research, explorative case studies were carried out. During the case research unexpected results can appear which would be less likely if more structured methods, such as surveys, were used. The literature survey was used to form a basis for interviews and in order to identify potential cases. Case studies were carried out in this manner in order to ensure that the research was relevant to OM practitioners and OM researchers.

Initial exploratory case studies were used to confirm the need for the research. Following the guidelines set out by Voss, Tsikriktsis et al. (2002) the cases will be in depth, unfocussed and based around a set of discussion points developed from the literature.

#### *4.3.2 Developing the Research Framework, Constructs and Questions*

This was done during the literature survey stage of the research project. The literature was used to form questions about the different approaches companies had taken when deciding how to take the decision to process or scrap a returned item. It was thought that the research framework would become more defined as case research was carried out and as the areas of interest of the Operations Managers became more clearly defined. A copy of the initial discussion points can be found in Appendix D.

#### *4.3.3 Choosing Cases*

Hussey and Hussey (1997) states that it is not usually necessary to find a representative case or set of cases due to the fact that this research will not be attempting statistical generalisations. For this reason cases were found using convenience sampling as described by Voss, Tsikriktsis et al. (2002). Potential case research companies were identified on the

basis of their current operations through consultants working in the field and through university contacts. It was anticipated that there would be very few companies in the UK that had fully integrated closed loop supply chains however it was thought likely that there would be many small companies that would form part of closed loop supply chains.

Informal conversations were held with existing University company contacts to identify those which could be used as case studies. A large number of cases were sought in order to make the resulting theory more relevant, interesting and as robust as possible.

It was thought to be important to study a variety of companies that process end of life equipment. These included companies remanufacturing their own products, third party remanufacturers and independent remanufacturers. It was considered that different levels of OEM cooperation might have a major impact on the way operations were carried out.

All companies that positive responses were received from were included in the research where practical. An explanation of each case lost or rejected is given in Chapter 5: The reason for this was that of replication logic described by Hussey and Hussey (1997) and Yin (1984). Yin (1984) states that studying cases similar to those already studied (literal replication) strengthens the theory and studying cases different to those already studied (theoretical replication) extends the theory. In general Yin (1984) confirms that more cases lead to the development of a stronger theory.

#### *4.3.4 Developing Research Instruments and Protocols*

The main research instrument that was used during the case research was semi structured interviews with production managers. Hussey and Hussey (1997) explains that interviews

permit the researcher to ask more complex questions and ask follow up questions, which is not possible in questionnaires. Hussey and Hussey (1997) goes on to state that an interview may permit a higher degree of confidence in the replies than questionnaire responses. For these reasons it was felt that interviews were a good method for collecting data from cases in the course of this research.

Data triangulation was carried out through direct observation, informal interviews with production staff and from company literature where available and relevant. Interview protocols were refined from initial case studies. A funnel model, as described by Voss, Tsikriktsis et al. (2002), was used for planning discussion points. Following this meant that questions at the beginning of the interviews were focussed on broad descriptions of the position of remanufacturing within the company. Questions towards the end of the interviews were focussed on how decisions are made during specific disposition decisions on the shop floor and the problems that were faced carrying out these operations.

#### *4.3.5 Conducting the Field Research*

Contact was made with companies using University contacts and with emails directed towards the production managers. Contact with companies was also made through a consultancy firm which specialises in remanufacturing operations, and at the time of the research was funded by the UK government to promote reuse and remanufacturing. It was thought that university contacts who have had good experiences with student projects in the past were likely to be positive to research requests. It was also thought that operations managers would be sufficiently senior to 'open doors' to the companies where necessary.

Set up visits were carried out before the more formal interviewing. This was to ensure that the broad objectives of the research and resource requirements were fully understood by all

parties involved before any more in depth research took place. The other aim of this was in order to prove that there was a need for the research.

Data triangulation was performed through direct observation of the process and process flow diagrams as well as informal interviews with production staff. This was to ensure that what the operations managers thought was happening on the shop floor was correct.

Data was recorded directly onto paper without the use of tape recorders. It was thought that interviewees might be put off by their presence and be concerned about confidentiality issues. Hussey and Hussey (1997) state that tape recording is very important during interviews. Despite this they do concede that interviewees may give a higher degree of frankness if the recorder is switched off during moments of confidential discussion.

Hussey and Hussey (1997) state that note taking during interviews can lead to omissions, distortions, errors and bias, where your own perceptions act as a filter on the data you record. In order to combat this, a copy of the full notes collected during interviews was sent to the interviewee soon after the interview for verification. The interviewee was invited to make modifications and to release the notes for subsequent inclusion in the thesis and publications.

In accordance with the suggestion from Voss, Tsikriktsis et al. (2002) the case studies were brought to a halt when there were small returns from each additional case study or interview. Once enough data had been collected to provide a reasonably comprehensive picture of the processes carried out and when there were diminishing returns, the interviews were brought to a conclusion. In the case of this research project only one meeting,

followed by clarifications by email, was required in for the majority of cases. Additional cases were sought until each of the categories in the framework presented in Chapter 6: was represented by at least two companies.

Interviews were carried out with senior members of staff in each case company. These were typically general managers, technical managers or managing directors. For a full list of interviewee job titles please refer to Table 9 located in Section 5.2. Where the interviewee did not have sufficient knowledge to describe their processes operational staff were requested to join the meeting. Meetings were typically 1-2 hours in duration and were followed by a plant tour where clarifications could be made directly with the process operators.

Many researchers question the validity of case based research for the reasons discussed by Flyvbjerg (2006) and mentioned in section 4.2. In the course of this research construct validity was ensured in two ways. Interviewees were asked to review case notes as soon as they were written up by the interviewer. Data was triangulated using plant tours and publicly available information about each company along with the interview notes. Explanation logic was used in order to improve internal validity. Multiple and diverse case studies were used in order to improve external validity. The reliability of the data collected was ensured through use of the case study protocol set out by Voss, Tsikriktsis et al. (2002).

#### *4.3.6 Data Documentation and Coding*

The notes collected during interviews were typed into electronic form directly following each visit to each company. They were then expanded to include more detail from the other

sources as detailed in previous section. The expanded notes were then sent to the interviewee for verification as soon as possible after the interview. This was done in order to address the potential for omissions, errors, distortions and bias discussed in the previous section. Summaries for each case study were generated in a standard format in order to aid comparison. These included flow charts showing the remanufacturing process in each of the cases. These flow charts can be found in Appendix F.

#### *4.3.7 Data analysis, hypothesis development and testing*

In his book, *Case Study Research: Design and Methods*, Yin (1984) gives detailed methods of how case studies can be effectively carried out in the social sciences. Eisenhardt (1989) builds on Yin (1984)'s work and presents a clear 'roadmap' for producing theory through case study research. As well as developing theory Eisenhardt (1989) describes how case study research can be used to test the theories that emerge. This section will detail how the data analysis and hypothesis development and testing were carried out in this research.

- **Analyzing within case data** – Case descriptions were written soon after case study meetings. These were sent to interviewees for validation. Process diagrams were drawn from each case description in turn.
- **Searching for cross-Case patterns** – Comparisons were drawn between process diagrams from each case. Common stages were added to a generic remanufacturing inspection diagram which is presented in Section 5.3. Comparisons were made between this generic process diagram and the specific processes used by each of the companies studied. Companies using similar process strategies were grouped into categories and reasons for the similarities were investigated using product and company dimensions. The resulting framework is discussed in Section 6.7.

- **Shaping hypothesis** – The hypothesis, that different remanufacturing companies, operate using different strategies was tested through replication case studies. Remanufacturers were found in order to strengthen the hypothesis and the framework which can be used to predict strategy for a given product. This was done through a validation study which is detailed in Chapter 8:

#### **4.4 Summary**

Case study research was found to be an appropriate method for descriptive research in immature research areas such as the one being studied in this research. This method was thought to be particularly useful for generating theory from practice. A framework for carrying out rigorous case based research proposed by Voss, Tsikriktsis et al. (2002) was followed in order to insure the resulting findings would be sufficiently rigorous to ensure they add a valid contribution to theory.

This chapter has detailed how exploratory case studies were carried out through interviews with operations managers. These took place in a range of companies which carry out remanufacturing, refurbishing and other material recovery opportunities where a disposition decision must be made. Where applicable these meetings were followed by more focussed and detailed interviews. A funnel model was used to plan interviews. The data collected from operations managers was triangulated through interviews with shift managers and visits to the factory floor.

An explanation for how the case study material would be used to generate theory in accordance with the method described by Eisenhardt (1989).



## **CHAPTER 5: ANALYSIS OF CASE STUDIES AND GENERIC INSPECTION MODELS**

The main objective of these case studies was to gain a detailed insight into the role and process of inspection carried out by remanufacturing firms. It aimed to establish the objectives of inspection and testing at all stages of the remanufacturing process and to investigate the possibilities of gaining the same process outputs through different means. A second objective was to learn from comparisons between the ways the different firms operate and the reasons for these differences.

### **5.1 Criteria for Selection of Cases**

Potential case studies were identified through university contacts and through a database of remanufacturers based in the UK, held by the Centre for Remanufacturing and Reuse. At the time of writing this was a project funded by the UK government with the aim of promoting remanufacturing and reuse. An email was sent to potential companies outlining the purpose of the research and the amount of involvement that would be required on their part a copy of this email along with the materials which were attached to it can be found in Appendix C. Further companies were contacted directly in an attempt to gain cases from different industries. In total nine companies responded positively to the request. One of these was based in Germany and so was not practical to meet with. One other, initially positive about the research, dropped out due to having a high workload. Since there were already two companies from the same sector (automotive) participating in the research it was felt that their absence would not cause a problem for the validity of the research at this stage.

Many of the cases studied did not describe their process as remanufacturing. For the purposes of this research the process was considered to be remanufacturing if it met the definition developed by Ijomah and Childe (2007) and discussed in Chapter 1 of this thesis.

All but one of the remaining seven companies involved in the research carried out processes that met this definition. The company which did not carry out these processes was a core broker, a company who collects, inspects, stores and sells cores to the Automotive remanufacturing industry. Although this company did not carry out remanufacturing it was a specialist in core level inspection and hence of great interest for this research. The following section gives some of the different characteristics of the companies that were studied.

## **5.2 The Cases**

The cases that were studied operate different business models and produce products for a wide range of customers. Some carry out remanufacturing on a not-for-profit basis and others remanufacture car parts directly for OEMs on a large scale. The table gives some of the characteristics of the different companies that were included in the research.

Company	Role of Interviewee/s	Size of Organisation	Amount of Remanufacturing	Customer	Products	Product Type Studied	OEM?	For-profit?
DefCo	Remanufacturing Manager	One facility	Small % of business	MOD	Defence	Mechanical/Electronic	OEM Approved	For-Profit
CopyCo	Manager, Environmental Health & Safety	Large multinational company	majority of business on site	Business	Copying/Printing Equipment	Mechanical	OEM	For-Profit
PCCo	Managing Director	One facility	100% of business	Business	IT Equipment	Electronic	Non OEM	For-Profit
GearCo	Commercial Director	One facility	20,000 units per year, close to 100% of business	OEM	Automotive	Mechanical	OEM Approved	For-Profit
ClutchCo	Technical Director	One UK facility	100% of production side of business	Business	Automotive	Mechanical	Non OEM	For-Profit
CoreCo	General Manager	Two facilities in EU	Core broker only / 0% Remanufacturing	Remanufacturers	Automotive Core Broker	Mechanical/Electronic	Non OEM	For-Profit
JetCo	Customer Support Operations Manager, Applications Engineer	One production facility, offices internationally	30-40 units per year / 33% of business approx	Business	Power Generation	Mechanical	OEM	For-Profit
CompCo	Production Manager	One facility	1,400-1,700 units per month / 100% of business	NGOs	IT Equipment	Electronic	Non OEM	Not-for-profit
MilCo	Managing Director, Manufacturing Systems Manager	Several UK facilities	1 batch of 768 per month / confidential % of business	MOD	Defence	Mechanical	OEM	For-Profit

**Table 9 - Overview of Case Study Companies**

It can be seen from Table 9 that the companies studied were from a large range of industries with different products and different business objectives. Not-for-profit organisation, CompCo, operates to give people in developing countries access to IT equipment. The remainder of the companies operate in a more conventional for-profit way. In the not-for-profit case this adds an interesting characteristic since many of their staff work as volunteers. The high number of remanufacturers in the automotive and defence sectors that were studied reflects the maturity of remanufacturing in these areas. The product type describes the component, module or product that was studied for this research which is not necessarily the main product the company produces. Some of the cases remanufacture a large volume of products and operate in a highly competitive market while others remanufacture smaller numbers of items and are known for their expertise and competency.

A full discussion of how the data was collected from cases can be found in the research methodology chapter, Chapter 4:. Full notes from the case studies can be found in Appendix E.

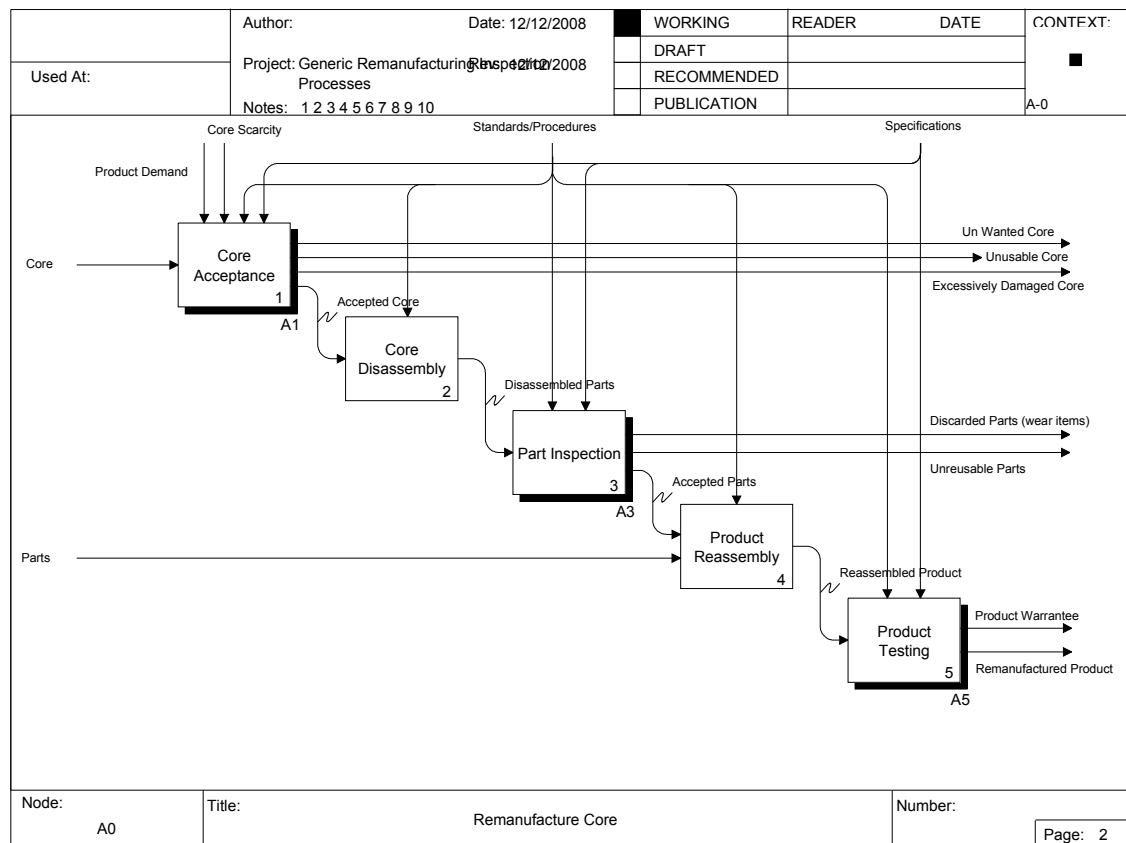
### **5.3 Development of a Generic Inspection Procedure**

A generic inspection procedure was developed from the case studies using the IDEF0 modelling format. The IDEF0 standard was used in preference to other modelling techniques such as flow charts because it allows decomposition, is easy to understand due to the simple graphics that are used, is precise and can be used with data abstraction. This is a particularly useful trait in the creation of a generic process diagram such as the one described in this paper. For a full discussion of the benefits of the IDEF0 standard in process modelling see Ang, Luo et al. (1995).

Flow diagrams for each case that was studied were created from the case studies. A copy of these diagrams can be found in Appendix F. These were compared and common stages of

inspection were identified. These common stages were renamed using generalisable terms in order to remove process specific terms. The common stages that were identified were added to an IDEF0 diagram. This procedure covers all processes that were observed in cases. Not all of the cases that were studied were found to carry out all of the processes shown in the diagrams. An investigation into the reasons behind these differences forms the following chapter.

The resulting generic IDEF0 diagram for remanufacturing is shown in Figure 6.



**Figure 6 - Inspection Processes within Remanufacturing Processes**

In the cases that were studied three key areas of inspection were found. Each of these is carried out at a different stage in the remanufacturing processes, as shown in Figure 6. It

should be noted, however, that not all stages are carried out in all processes. The reasons for this are core to the aims of this research. A full discussion of these reasons is given later in this chapter.

The three stages of inspection that were identified were:

- Core inspection/testing
- Part inspection/testing
- Finished product inspection/testing

There are parallels between this and what is typically done in forward manufacturing. As it was discussed in Section 3.1.1 inspection in forward manufacturing typically takes place on materials entering the process, during the process and on the final product. One key difference between the model presented here and that produced by Dale (1999) is the number of items that are rejected. Shingo (1986) talks of finding defects that are one in a thousand or more. In the case of remanufacturing items that must be removed from the process are much more common indeed. GearCo stated that *“There are no parts at all that are never replaced.”*

According to Brent and Steinhilper (2004) remanufacturing always requires 100% inspection rates at one or more stages during the remanufacturing process. This is what was observed in all of the cases that were studied. This is in contrast to some new product manufacture where sampling methods are used. Section 3.1.2 gives a discussion of when different amounts of inspection can be used in forward manufacturing. During the case studies 100% inspection was observed to be carried out on cores and disassembled parts as well as the finished products themselves. It was commonly stated that this done to increase the second user’s confidence in remanufactured products and it is thought to partly explain

why remanufactured products often appear to be more reliable than new, as discussed by Steinhilper (1998). Dale (1999) explains that the ideal situation in forward manufacturing would be to inspect all products and thus make absolutely certain of quality this is what is currently done in remanufacturing processes.

Each of the three stages of inspection has different objectives. The objective of core inspection and testing is to remove cores that will be uneconomical or impossible to remanufacture. This improves the reliability of the population of items that are produced and ensures that cores that are uneconomical to remanufacture do not enter the process.

The second stage of inspection is carried out once the core has been disassembled. The aim of part level inspection and testing is to remove non reusable components from the product. This has the effect of increasing its reliability once it is reassembled. These parts may be non reusable because they have already failed or are likely to fail within the next product life.

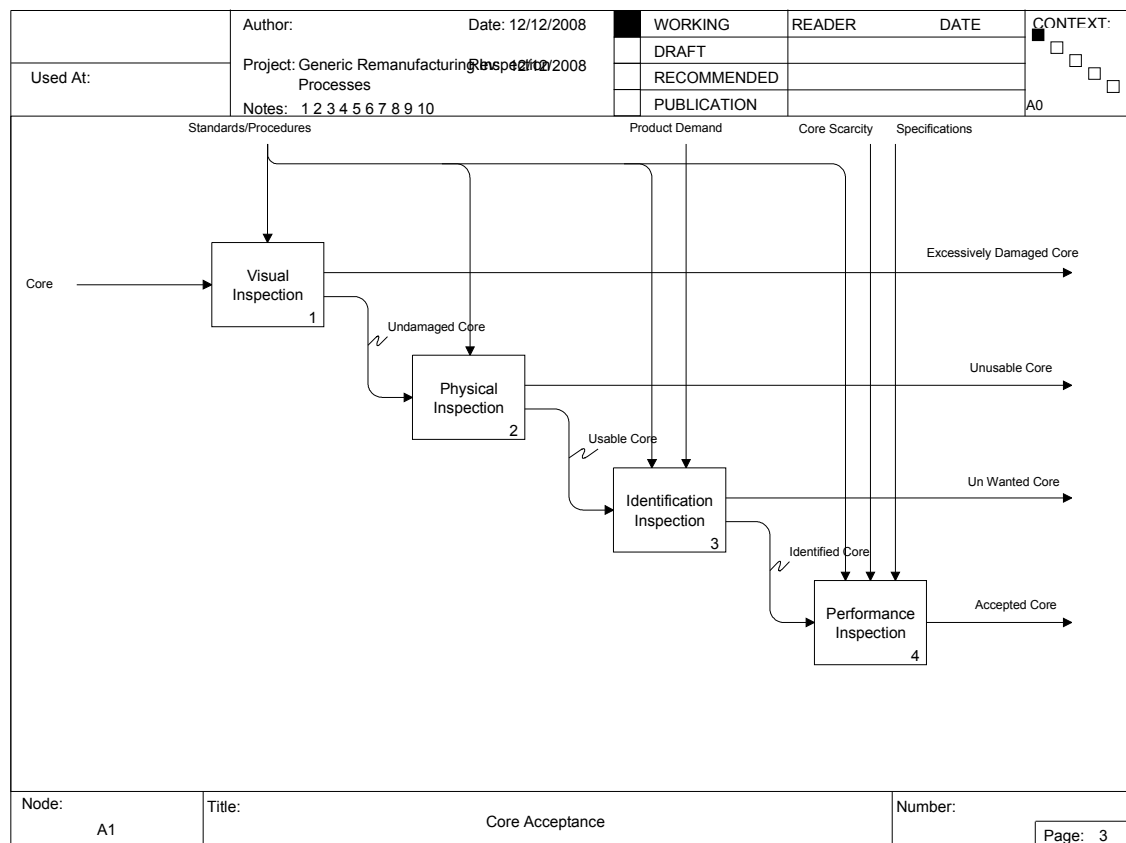
The final product inspection stage is carried out to ensure that the products are in full working order before they are shipped. Products that fail this stage are reworked before being retested and sold.

All of the inspection and testing procedures are carried out in order to gain confidence in the ability of a product to perform throughout its second life. Without these procedures it would be difficult to ensure the quality of the products produced and to offer full 'as new' warranties as are required for remanufactured products. This could potentially lead to a

lack of consumer confidence in remanufactured products and excessive warrantee costs to the remanufacturer.

### 5.3.1 Core Inspection

Cores are usually inspected as soon as they arrive at the remanufacturing facility. The following figure shows the details of how this inspection is carried out.



**Figure 7 - IDEF0 Diagram of Generic Core Inspection Procedure**

The figure shows the four main tasks in the core acceptance procedure that were identified. The first is a visual inspection. This is carried out simply through looking at a core and deciding if it has obvious major damage which would make it unremanufacturable. During an interview with MilCo it was stated that items “*that had been run over by a fork lift truck*” would be rejected at this stage.

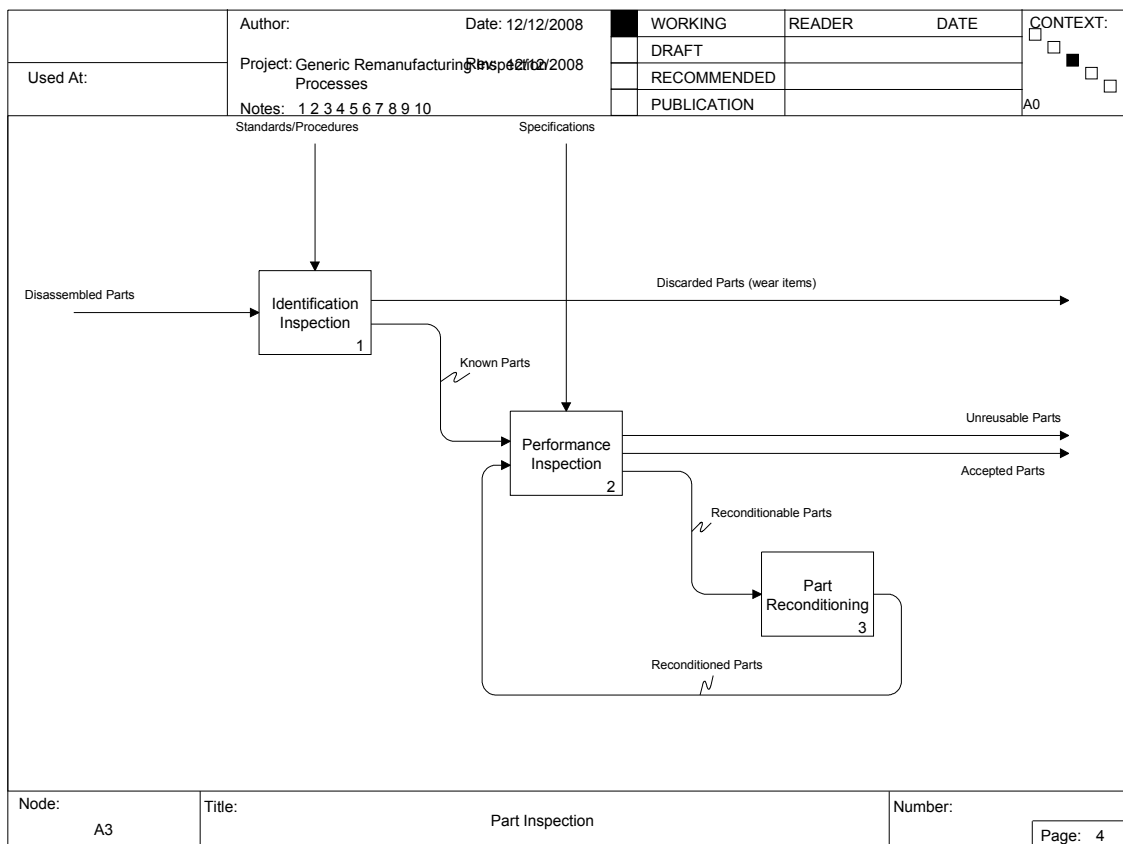


Cores that have no obvious signs of major damage are subjected to the second test in the procedure. This has been shown in Figure 7 as the physical inspection. Again this is still done manually but the actual process varies depending on the core being inspected. For automotive components two main methods are commonly used. The first is to attempt to rotate any part of the product that should normally move and the second to smell electrical components to test for burn out. This process was termed “*Scratch and Sniff*” during the interview with CoreCo. Cores that fail this test are sent for recycling and/or disposal.

The third stage of the process is to identify the part type and part number of the core. This is used in order to estimate the demand for and value of the product after it has been remanufactured. Cores for which there is no demand are disposed of at this stage. The fourth and final task within the core acceptance procedure aims to assess the performance of the core. This is usually done using test rigs specifically designed for the procedure. The standards the product must meet are set by industry bodies, international standards, OEM producers or the remanufacturing firm themselves. The aim of this process is twofold; firstly to establish whether the core is economical to process and secondly to establish whether the finished product is likely to conform to specifications once it has been remanufactured.

### *5.3.2 Part Inspection/Testing*

Once cores have passed the core inspection and testing procedure they are sent for disassembly. The cores are disassembled and thoroughly cleaned. After this the parts are passed to the second set of inspections and tests. The process diagram for this process is shown in Figure 6.



**Figure 8 - IDEF0 Diagram of Generic Part Inspection Procedure**

It can be seen from the diagram that some of the tasks are similar to those carried out at the core level. Firstly the part is identified. If, according to company procedures, it is a part that is always replaced then it is discarded immediately. These are usually wear components and are often the reason for previous user discarding the product. Parts that are sometimes reused are sent through a performance inspection process. Typical activities in this process include measurement and leakage testing. If they are found to not conform with required specifications then they are either discarded or reconditioned. During the case study interview with MilCo it was stated that:

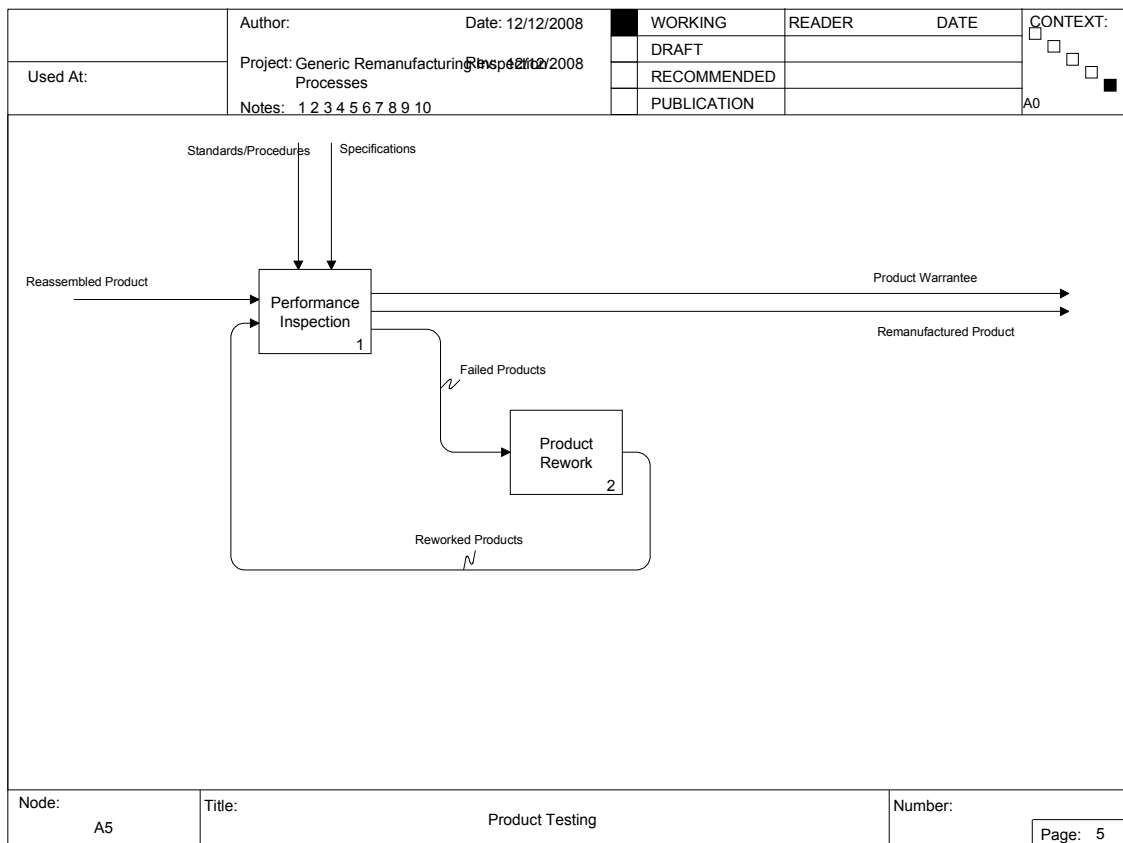
*“it is often quicker to recondition a part in house than it is to wait for a new one to be made”.*

A similar comment is made by Depuy, Usher et al. (2007). This is especially the case when small numbers of parts which are not mass produced are concerned. After reconditioning parts are inspected once more for performance in order to ensure they meet requirements.

Once the quality of parts has been assured, they are passed to the next stage of the remanufacturing process. Additional parts, either reconditioned or from other sources, are used to replace the ones discarded in the previous inspection stage and the product is reassembled. Once it is reassembled it is passed through to the third and final stage of the inspection procedure, the product testing stage.

### *5.3.3 Final Product Inspection/Testing*

The following diagram shows the stages of inspection which are carried out once the parts have been reassembled into the remanufactured unit.



**Figure 9 - IDEF0 Diagram of Generic Final Product Inspection Procedure**

In this final stage of inspection, finished products are tested against set criteria. This is a very similar process to new product manufacture where products are tested before they are shipped. Products which fail the performance inspection are reworked and retested before they are sold.

It can be seen that performance inspection is once again the key part of this inspection and testing process. This is the final stage at which the reliability of the final product can be estimated and/or ensured. The process and standards carried out during the performance inspection are different for each product. In the case of OEM approved remanufacturers these are developed with the involvement of the OEM for the product concerned.

#### *5.3.4 Discussion*

This section has presented a generic inspection procedure developed from case studies carried out with companies carrying out remanufacturing operations. The following chapter will compare this generic process with individual case studies. The aim of this is to identify techniques that are used to increase the efficiency of the inspection and testing procedures identified in this section.

### **5.4 Chapter Summary**

This chapter has presented the findings from case study interviews with nine different companies engaged in remanufacturing. Through these case studies the acceptance procedures for cores, parts and finished products within remanufacturing processes have been identified. This chapter has described the aims of each stage of the inspection procedures, the information gathered and how it is used. The following chapter discusses the findings of the cases further. It explains the key differences between the cases and uses them to develop remanufacturing strategy framework.

## **CHAPTER 6: REMANUFACTURING STRATEGIES**

## **INSPECTION**

The following section outlines the differences between the case studies and the generic model presented in the previous chapter. It attempts to find reasons for these differences in order to show opportunities for other companies to use similar processes. It concludes with a remanufacturing strategy framework showing why different inspection procedures are followed for different products.

### **6.1 Reason for Product Return - Electronic vs Mechanical Products**

Major differences were identified between the way electronic and mechanical products are remanufactured. The cases of electronics remanufacture that were studied do not fit into the definitions for remanufacture provided by the Automotive Parts Rebuilders Association, APRA (2008) or The Remanufacturing Institute (2008) since they do not always include disassembly and rebuilding of the product.

Despite this they meet the definition set out in Chapter 1. The products are expected to perform as they would have done when they were new for a full second life. In addition to this the warranties offered by the companies carrying out the remanufacturing are as extensive as those offered by OEMs for new products.

It is the case with all the electronic product remanufacturers studied that disassembly is carried out only to facilitate repair as and when it is necessary. All other operations required to guarantee the reliability of the product are carried out without disassembly. In addition to this the vast majority of the computers that are remanufactured by CompCo and PCCo are

fully working and so disassembly would serve no purpose at all in the majority of cases. This is largely due to the fact that the main reason for discarding these types of product is not due to it wearing out but due to break down or the product being no longer fit for purpose in its current setting. Complete disassembly is not always necessary, and can be detrimental if the item is already full functional and reliable. The common phrase “If it ain’t broke, don’t fix it!” applies in this context, where disassembling working items could make them work less well. Items which are still working or which have a non wear out failure can be repaired where necessary and tested to ensure that they are reliable for the duration of another use period.

In the case of mechanical product remanufacturers, every core that is processed is disassembled. This is necessary in order to assess the state of the parts within the item and to carry out repairs and replacements where necessary.

If the reason for a mechanical product’s return is known then it might be unnecessary to completely disassemble it. When a new product fails very early in its life or during final product testing the failed component is fixed, it is retested and is sold with the expectation that it will be as reliable as a new product. This is commonly done in rework loops of new-manufacture processes when products fail inspection procedures. There should be no reason why this cannot be done for non-worn-out products that are slightly older, if a full warrantee can still be offered. This would allow remanufacturing companies to reduce the number of costly disassembly processes they currently carry out.

In order to do this the products in question must be subjected to specific processes developed in order to bring the product to a functional state and to assure their reliability. In

the case of mechanical products processed by companies such as GearCo and ClutchCo this is done through the replacement of excessively worn parts. In the case of CompCo and PCCo this is done through use analysis, age estimation and the use of diagnostic software.

It does not matter how it is done, what is important is that the remanufacturer is sufficiently confident that their products will continue to perform as predicted these products could be classed as remanufactured.

Remanufacturing processes for computers, observed in CompCo and PCCo, use methods other than disassembly to ensure the reliability of the products. There is potential for these techniques to be used to remove the need for and cost of complete disassembly in the remanufacturing of some other products. This may be through utilisation of information from the product itself through “green ports”, a product mounted chip which contains use information about the product described by Nagel and Meyer (1999) or perhaps directly from the previous user as was the case with CompCo.

## **6.2 High Value vs Low Value Core – Core Scarcity**

It was noticed that performance inspection was not carried out at the core level in some of the cases, MilCo, GearCo and JetCo. This appeared to be due to the value or rarity of the core. In these cases the feasibility of remanufacture of the core was more important than the cost of remanufacture.

In high value core remanufacturing very few cores are discarded during the core level inspection stage. In some cases the customer expects to receive the exact same core they supplied to the remanufacturer. Reliability of products in these cases is ensured through



extensive testing at part and product level rather than by elimination of ‘bad’ cores in the population.

Inspection at the core level is often limited to identity inspection and visual inspection alone. In one of the cases, where cores are returned in large batches, this was done for a batch at a time.

There appeared to be a link between the value of a core and the tendency for a company to dispose of it. There was a much higher tendency to dispose of cores in high volume, low core value processes, such as PCCo, CompCo and CopyCo, than there was in lower volume and higher core value processes such as DefCo and MilCo.

### **6.3 The Role of Core Brokers**

The following details are based on information gathered from CoreCo, a core broker from the automotive remanufacturing industry. For a full version of the notes collected during the interview please refer to Appendix E.

Remanufacturers have four main routes through which they source cores:

1. Swap out exchanges – where a remanufactured product can only be purchased with the surrender of the failed unit. This usually must be done within a certain time limit.
2. End-of-life disassembly plants – where products are disassembled and saleable parts are removed before shredding for materials recycling. This is a major source of cores in the automotive remanufacturing industry.

3. Core brokers – specialist companies that source, store and supply cores largely obtained from disassembly plants.
4. Direct from customer – product sent direct by owner or user. These are sometimes returned to the customer after remanufacture and sometimes not. Customers supplying cores in this manner either use it as a disposal route or they require an item they own to be remanufactured. Ownership of the core in the latter case remains with the customer throughout the remanufacturing process.

Most companies studied were found to use either; a combination of the first three to balance the type and number of each core they require (eg ClutchCo and GearCo) or they remanufacture only what they are sent by their customers (eg PCCo and DefCo).

Companies that operate using cores from the first three sources are commonly found in the automotive industry. All of the cases from other industries were required to process the cores they were provided with by customers and not to source cores from brokers or other locations. In some cases, including the DefCo and MilCo, they return the same products to the original customer and in others, including CopyCo and PCCo, they sell to a new user.

The core broker that was studied based its business on their expertise at locating, collecting, identifying and inspecting automotive cores. They carry out inspection at the core level in order to dispose of unremanufacturable cores. In this case, the first three stages of the core acceptance procedure, shown in Figure 7, were carried out twice. The first time it is done is in order to determine if the cores are worth purchasing. This is done at the location of the cores before they are bought and shipped to the company. The second time it is to ensure that only useable cores are sent to the customer. Any cores that are found to be unsuitable at

the second stage that were not at the first stage must be scrapped at cost to the broker. Brokers increase the value of a core by gathering knowledge about its condition through inspection procedures.

It was found that some cases that use cores exclusively from core brokers do not carry out all of the core level inspection stages identified in the generic model. If a core is disassembled and a fault is found that should have been identified by the core broker then it is rejected at cost to the core broker. Due to this guarantee by the broker, the only core level inspection tasks that are carried out in these companies are the visual inspection, in order to identify damage caused in transit, and the performance inspection if required.

Some of the cases that were studied were found to only occasionally source cores from the brokers. The most common reason for this was in order to obtain rare cores. These companies were found to subject all cores to the same process regardless of source. Core brokers offer a specialist service which includes carrying out the core level inspection procedure. They are experts in their fields and carry out some inspection procedures on behalf of their customers.

#### **6.4 Not-For-Profit vs For-Profit**

Two companies were studied which process end of life IT equipment. CompCo operates as a 'not-for-profit' business. They supply equipment to NGOs in developing countries and the majority of their shop floor staff work on a voluntary basis. PCCo operates on a more conventional 'for-profit' basis. It offers a service to its clients to audit, wipe and dispose of their used IT equipment. If the client requires, PCCo will sell the remanufactured equipment on the client's behalf. Both companies operate using the inspection stages

outlined in this chapter however CompCo remanufactures almost of the equipment it receives whereas PCCo is very selective about which equipment it thinks it can sell and hence what it remanufactures. It is required to inspect all of the equipment it receives.

These companies were found to have very different ways of coping with the large volume-low value aspect of their business. As it was discussed in section 6.1 electronic equipment is not completely disassembled during a remanufacturing process. This was found to be the case for both of the companies.

CompCo reduces the volume of cores it has to deal with at source. It issues strict guidelines for the specifications and functionality of equipment it will accept. Any equipment supplied that does not meet these requirements is recycled at cost to the client. Additional costs incurred by CompCo are also charged to the client in this situation. Software is run on each PC, by operatives working on a voluntary basis, to find faults and format the systems.

PCCo must process all of the equipment it is supplied. It has developed software which is based on a network. Equipment plugged into the network is automatically processed. The software audits the equipment, finds its type, specifications and functionality. If required it also formats the equipment, installs operating systems and makes it ready for second use.

It was observed that the two cases processed the equipment in much the same way but using different methods. As CompCo is a not-for-profit organisation it is able to make high demands for the specifications of equipment it receives. It can do this as it helps its customers by disposing of some of their IT waste for them at very low cost. This is in contrast to PCCo which is paid to dispose of its entire client's IT waste. Its status, as a not-

for-profit business means it can recruit volunteers to do many of the more labour intensive tasks in the process. PCCo must accept all of the equipment they are supplied and so have developed a less labour intensive technology based solution to deal with the same volume problem.

## **6.5 OEM Partner vs Non OEM Partner**

GearCo remanufactures automotive drive train systems for most major car retailers. They supply replacement parts to be fitted to cars by OEM dealerships during the car's warranty period. Working directly for the OEMs in this manner allows the company to access a great deal of information about the products it is remanufacturing direct from the OEMs. Through the partnership stringent performance tests during the product and part level inspection processes have been developed. This partnership is beneficial to GearCo however it also places other requirements on the firm. All parts that are discarded during the part level inspection must be replaced with OEM parts. Due to procedures established in collaboration with the OEMs, parts that are found not to meet specifications may not be reconditioned and must be scrapped and replaced. This is done regardless of whether a reconditioned part would perform as required. There is potential for cost savings in this area that cannot be accessed.

## **6.6 Additional Findings from Cases**

In the past ClutchCo carried out core level performance inspection prior to disassembly however it now does not. It is thought that, at the time, this was carried out in order to eliminate cores that would otherwise take up capacity in the remanufacturing line while not contributing to output. Core volume is now much lower and the core testing procedure is no longer carried out. Final performance inspection is also not carried out after the product has

been reassembled. CluchCo feels that thorough testing prior to reassembly is sufficient to ensure product quality and reliability.

While many of the companies that were studied carry out inspection at all three stages identified in Figure 6, the ClutchCo case appears to show that there is a trade off between the processing of cores that cannot be sold and the cost of carrying out the inspection itself. Thus some cores are processed that would otherwise have been rejected. Three stages of inspection ensures that the quality of the products are high but may be excessive in some cases. The only test that is required to ensure reliable products are shipped, and to protect the consumer, according to Shewhart (1931) is the final product testing process.

## **6.7 Proposed Strategy Framework**

Key differences were identified in the way case study companies carry out their inspection and testing processes during remanufacturing operations. These differences were made clear through comparison between the generic inspection model shown in Chapter 5 and the specific inspection procedures carried out in each of the companies. Many of the differences are due to product specific reasons, constraints from the products' OEM, customer quality demands or time constraints.

These were observed as being due to core value and the reason for return of a core, i.e. the core's condition. Core value can be used interchangeably with scarcity of core. If cores are relatively common, disposal is an effective way of increasing the reliability of the population as a whole. This was observed in the cases of PCCo and CompCo. If cores are scarce they must be processed almost regardless of cost. This was seen in the cases of MilCo and DefCo.

In the case of low value cores there is often a new alternative that can be purchased in its place. The cost of remanufacture must not exceed this or the customer will certainly buy a new product instead. In the case studies it was regularly stated that the sale price of a remanufactured product must be less than 60-80% of the cost of a new product for consumers to accept it.

If cores are rare the situation is very different. It is often the case in the defence industry that it is impossible to get a new unit made at any cost. The alternative to a remanufactured product is to upgrade a wider system, such as an aircraft, to accept a new unit. The cost of upgrading the wider system is often so high that it is not considered during the remanufacturing inspection process itself. If it is feasible for a product to be remanufactured, and new products cannot be made, then it will be almost certainly be done regardless of cost.

The reason for the return of a core is the second main variable that has been identified. The reliability of a new, fully working product would not be increased by complete disassembly and reassembly of it. In the same way, a product with a long life expectancy does not need to be disassembled to be remanufactured so long as it is found to be fully working or if a minor fault is repaired. In contrast products that have failed due to a worn part need to be carefully inspected on a part level to ensure that other components are not also close to failure.

Wilkins (2002) describes how electronic products such as computers are currently designed for a life far longer than they are used for. It is estimated that many electronic products,

such as computers and mobile phones, will not enter the wear out phase of the reliability curve for ten or more years. It is currently rare that products such as these are used for so long however this may become more common in the future as the technology matures, obsolescence becomes less of an issue and the products enter the maturity phase of their respective product life cycles. This gives an idea of why the electronic products seen are returned because of obsolescence or failure and not usually due to wear out.

### 6.7.1 Strategy Framework

The following diagram shows the main strategies that were observed in the case study companies.

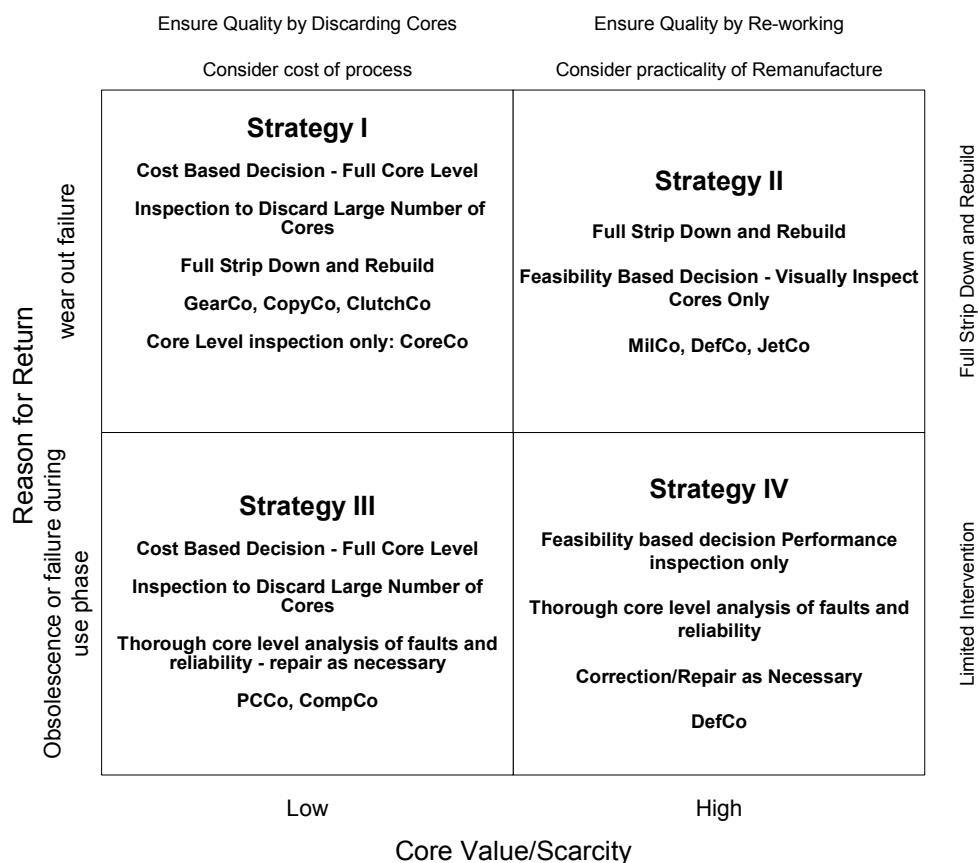


Figure 10 - Remanufacturing Strategy Framework



The axes that were chosen for Figure 10 reflect the main reasons that appeared to lead to the different strategies used by the case studies. What follows is a description of each of the four strategies shown in the framework above.

#### *6.7.2 Strategy I*

This strategy includes all of the processes shown in the generic process. A cost based decision is used to identify the most economical cores for remanufacturing. A large part of this is an assessment of the amount of work required to process the core. This is done through simple tasks such as testing to see if relevant parts move smoothly. Once accepted cores are fully disassembled and parts are inspected. All cores are processed in the same way. This has been described by Richter (1997) as the ‘Bang Bang’ approach.

#### *6.7.3 Strategy II*

When cores are scarce less emphasis is put on core inspection. The aim of this process is to establish if it is possible to remanufacture a given core rather than if it is economical. This is usually done at a core level using a simple visual inspection. It is sometimes the case that an individual core will be remanufactured at a loss if that means the maximum lead time for a given contract is not exceeded. Once considered feasible all cores are disassembled and inspected following a process similar to Strategy I.

#### *6.7.4 Strategy III*

This strategy relies heavily on discarding unsuitable cores in large numbers at the earliest possible stage. Cores that are un-sellable once processed perhaps due to their age and/or demand will be rejected immediately. Borderline cases that do not pass a turn on test will also be discarded. Only those cores with high value fail the turn on test are analysed further. Faults are identified and those that are deemed economical to repair are processed.

Disassembly is only carried out to the level required to replace the failed component or components. Cores are not routinely disassembled. Final product testing is used to ensure the product will function for a full second life.

#### *6.7.5 Strategy IV*

As with Strategy II the main aim here is to assess the feasibility of the remanufacturing of a given core. Less emphasis is put on some of the inspection procedures however the performance inspection is critical for finding the faults with an item and in some cases providing a quote to the customer for the work. As with strategy III disassembly is only carried out in order to facilitate the replacement of failed components and final product testing is used to ensure the product will function for a full second life.

### **6.8 Chapter Summary**

This chapter has presented the findings from case study interviews with nine different companies engaged in remanufacturing. It has made comparisons between the cases and gives a remanufacturing strategy framework that explains how these decisions are made. It concludes that remanufacturing strategy decisions are based on the reason for failure of a product and its relative value or scarcity. This chapter also outlined several techniques that could be used to increase the efficiency of remanufacturing processes. The following chapter gives details of the validation method that was used in order to improve the robustness of the theory for remanufacturing strategies and the framework that have been presented in this chapter.

## **CHAPTER 7: MODEL VALIDATION METHODOLOGY**

The previous two chapters have presented a generic inspection process model and framework for remanufacturing strategy. The model, showing the main stages, objectives and outcomes of inspection within remanufacturing can be used to aid understanding of the role of inspection within remanufacturing.

The framework characterises the remanufacturing processes within companies. It uses the two variables, reason for return and core value. Each of the four strategies in the framework has a corresponding IDEF0 model. These can be used together with the framework in order to aid remanufacturers in improving their processes and by companies new to remanufacturing in establishing them up.

The model and framework were validated using a group of practitioners contacted through a consultancy firm specialising in remanufacturing. Originally the plan was to present the findings at a practitioner conference, organised by the consultancy firm, on the subject of inspection in remanufacturing. A survey would be issued directly following the presentation through which the audience could deliver their responses to the research. This conference was postponed several times and so an alternative plan, to visit the practitioners individually using the same questionnaire, was carried out instead.

A presentation was given individually to each practitioner describing the model, how it came about and its potential uses. The practitioners were then asked to fill out a short questionnaire. The aim of this questionnaire was two fold, firstly to assess the practitioners'

understanding of the model and secondly to evaluate its relevance to them. Its relevance was assessed according to the five properties of relevant research defined by Thomas and Tymon (1982). Although the work produced by Thomas and Tymon (1982) is now quite old, it is far from outdated. Papers written by Platts (1993) detail how lack of industrial relevance is still a major issue in operations management research and outline similar properties.

## **7.1 Methodology Selection**

A theory testing survey was chosen as the most appropriate method for validation of the model. This was due to the fact that there was a theoretical model that required testing from the earlier phases of this research project. Due to the calls for improved quality and more appropriate use of survey research in Operations Management, Forza (2002) produced guidelines which will form the structure for the remainder of this section. He states that *“theory testing survey research takes place when knowledge of a phenomenon has been articulated in a theoretical form using well defined concepts, models and propositions.”*

## **7.2 Construct Selection**

The purpose of the questionnaire was to find out if this research is both practically relevant and useful to practitioners. Thomas and Tymon (1982) identified five necessary properties which research must demonstrate in order for it to be useful for those whom it is intended. These are descriptive relevance, goal relevance, operational validity, non-obviousness and timeliness. Definitions for each of these properties, adapted from Thomas and Tymon (1982), are given below:

***Descriptive relevance*** refers to the accuracy of research findings in capturing phenomena encountered by the practitioner in his or her organisational setting. In other words, do the models produced in this research reflect what is observed by the practitioners?

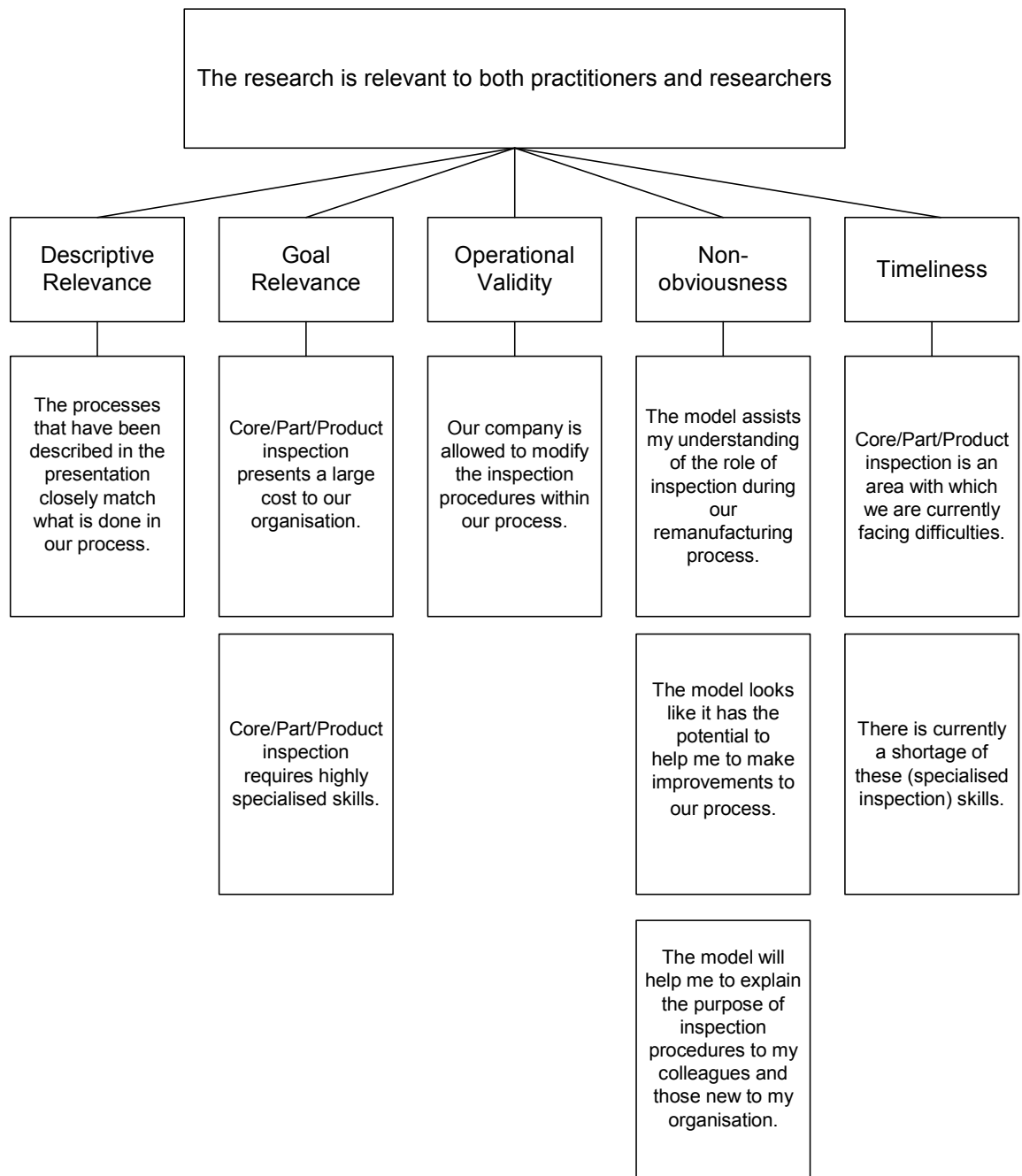
***Goal relevance*** refers to the correspondence of outcome (or dependent) variables in a theory to the things the practitioner wishes to influence. In other words, does the research address something that the practitioner deems to be a problem?

***Operational validity*** concerns the ability of the practitioner to implement action implications of a theory by manipulating its causal (or independent) variables. In other words, is it feasible for the suggested changes be implemented.

***Non-obviousness*** refers to the degree to which a theory meets or exceeds the complexity of common sense theory already used by a practitioner. In other words, does the practitioner feel that the model helps him in his decision making?

***Timeliness*** concerns the requirement that a theory be available to practitioners in time to use it to deal with problems. Does this theory address a current, or future, problem?

For the purpose of the questionnaire, each of these properties was converted into research specific questions. The following figure gives details of the questions that were used for the questionnaire and which properties they aimed to address.



**Figure 11 - Questionnaire Question Categories**

It can be seen from Figure 11 that the questions asked were directly based on Thomas and Tymon (1982)'s five necessary properties of relevant research which were described earlier in this chapter. As shown in Figure 11 some categories were addressed with a single question whereas others were addressed using a larger number of questions. This was done

to enable the questionnaire, shown in Appendix J, to fit on two pages of A4 and ensure that a high proportion of subjects would respond.

Only one question was used in order to address the accuracy and the operational validity of the research. The researcher was present during the completion of the questionnaires and it was made clear that the questions should be answered honestly but clarification of the meaning of questions could be given. For these reasons it was thought that asking questions repeatedly was unnecessary.

As shown in Figure 11, some of the other categories required more than one question. This was due to the complexity of the issues that were being asked about. At the time of writing it was thought that the model could be of use in many different scenarios. In order to access the non obviousness of the research it was felt that questions should be asked relevant to each of these scenarios.

Goal relevance has two questions for a similar reason. The project aimed to reduce the costs of inspection but also to increase its capacity. If the respondents noted that they had a shortage of inspection skills then it would follow that making more efficient use of the labour they currently had would be beneficial to them. It could be the case that although inspection itself does not present a large cost to the business, it does require skills that are in short supply and hence creates a bottleneck which would restrict growth of the company.

Timeliness is another category which it was thought should be addressed using more than one question. The first related to any problems the company might be currently facing with inspection whereas the second addressed potential shortages of skills which are required.

### **7.3 The Draft Questionnaire**

A draft questionnaire was formed based around the factors discussed in the previous section. The questionnaire was formed in three main parts: an introduction including opening questions asking for organisational data, questions aimed at assessing the respondents understanding of the model and finally the questions shown in Figure 11.

After some instructions, the initial questions aimed to collect respondents' basic data. They asked the role of the respondent within the organisation, the type of products they remanufacture and the scale of their operation. The second stage of questions aimed to assess the respondents' understanding of the research. It did this by asking sufficient questions for the author to fit the company to the model produced by the research. These included questions relating to the state of cores when they are returned and the tendency of the company to scrap them. The questionnaire then asked the respondents to locate their organisation within the model. It was thought that this was an important stage of the process so that the questions relating to the relevance of the research were answered based on a sound understanding of it.

The third and final section asked questions relating to the Thomas and Tymon (1982) relevant research factors that were discussed in section 7.2.

Most responses were collected using a six point Likert scale. The reasons for selecting the six point scale were to force the respondent to give a positive or negative response without forcing them too far from neutral. Positive and negative phrasing of questions was



alternated in order to maintain the interest of the respondent and reduce the tendency of respondents to mechanically circle points towards one end of the scale.

Questions to assess the respondent's understanding of the model were asked twice in order to ensure the accurate response was obtained. In order to obtain a high response rate questions were limited to 20 words in length, a guideline that is stated by both Sekaran (1992) and Forza (2002). The total number of questions was kept to a minimum, 22 for the first draft, and closed questions were used where a response was required.

Respondents were invited to give open ended comments at the end of the questionnaire. The questionnaire was deliberately designed to fit on one two sided A4 sheet of paper in order to encourage a high response rate thereby reducing the chance of non response bias. Due to the fact that there was a need for quick results convenience sampling was used to identify respondents. A discussion of this is made by Forza (2002). It was thought that this would not create an insurmountable problem for the survey as it is intended to give an idea of the relevance of the model created during this research and will not be used to prove any new concepts. No claims of statistical significance will be made from the results.

#### **7.4 Application of the Research Tool**

Data was collected during meetings with practitioners on their own premises. A presentation was given describing the model. It was followed by instructions about how to fill out the questionnaire. Respondents were then invited to fill in the questionnaire whilst the author was available for assistance and clarification on questions. In addition to the data collected using the questionnaire, case notes were taken during the meetings.

The questionnaire was put through three stages of review before it was given to the practitioners. This method is recommended by Forza (2002). All of the questions were pilot tested by colleagues, industry experts and finally by a member of the target audience.

## **7.5 Final Questionnaire**

Following piloting with two colleagues, two academics and one practitioner, a method recommended by Forza (2002), a final questionnaire was produced. The main changes that were made to the questionnaire related to the intended meaning of the questions. There was a particular problem with the use of the phrase ‘core’ to describe a returned product. Depending on the industry in question this could be called a core, return, end of lease item as well as other specific terms such as a body or a dead body. In order to get around this a description of the intended meaning of the word core was added to the model description document. This was also clarified during model presentations to practitioners. A full copy of the description notes, on which presentations were based, and the final questionnaire incorporating these changes can be found in Appendices G and J respectively.

## **7.6 Summary**

This chapter has discussed the creation of the questionnaire which was used to assess the relevance of this research to practitioners and researchers alike. It has detailed how the questions in the questionnaire were derived from Thomas and Tymon (1982) five necessary properties of relevant research. The following chapter will give the results of the questionnaire and discuss their implications for the research.

## **CHAPTER 8: MODEL VALIDATION RESULTS**

Meetings were held with a total of nine companies for the validation stage of the case research. The first part of this chapter will report on the details that were recorded during the case study meetings. The second part will report and discuss the data that was collected using the questionnaire tool. This chapter will present result which will compare the companies discussed with the remanufacturing strategies described in the previous chapter. These are Strategy I, for low value, worn out products, Strategy II for high value, worn out products, Strategy III for low value products that are not worn out and Strategy IV for high value products that also not worn out.

A request was sent to companies engaged in remanufacturing through the database held by the Centre for Remanufacturing and Reuse based in Abbingdon, UK. In total twelve positive responses to the request were received.

Unfortunately it was not practical to visit one, a trade association based in Australia. Two of the other respondents were also not met with due to their being located in France and Germany. It was thought that this would not cause any problems with the research due to the fact that companies remanufacturing similar products had already been extensively covered in the UK.

In addition to the industries within which the framework was developed the validation process included companies engaged in clothing repurposing, end of life consumer goods treatment as well as one major UK retailer that was at the time investigating the potential role for remanufacturing within its commercial returns treatment process. It was thought

that validation should be carried out with companies in sectors not covered during the development of the model in order to assess its generalisability.

The following table shows an overview of the companies that were studied during this stage of the research.

<b>Company Name</b>	<b>Product</b>	<b>Electronic/Mechanical</b>
CompressorCo	Compressors	Mechanical
VacCo	High Vacuum Pumps	Both
WasteCo	Televisions (also processes all types of WEEE)	Electronic
FlightCo	Aerospace Flight Control Units	Mechanical
RetailCo	Kettles & LCD TVs (also processes other consumer products)	Electronic
ClothesCo	Remade Clothing	Neither
TonerCo	Toner Cartridges	Mechanical
GearCo	Manual Transmissions	Mechanical
AltCo	Rotating Automotive Electrics	Mechanical

**Table 10 - Companies Interviewed for Model Validation**

It can be seen from Table 10 that only one of the companies used for validation, GearCo, was involved at earlier stages of this research. Many of the companies were well established and had been operating for decades. WasteCo is relatively new to remanufacturing and at the time of writing its processes were undergoing extensive development. At the time of writing RetailCo had not established their processes but planned to in the near future. Their answers to the survey were based on two systems they have designed rather than one that is already operating. This case was still thought to be relevant since the interviewee, who had designed the systems, had extensive knowledge of a similar system at a different retailer.

## **8.1 CompressorCo**

CompressorCo are a small 3<sup>rd</sup> party remanufacturer of compressors based in southern England. They remanufacture any make of compressor for business customers. The compressors are used for refrigeration and air conditioning type applications and range from 1/3 to 60hp in terms of their power output.

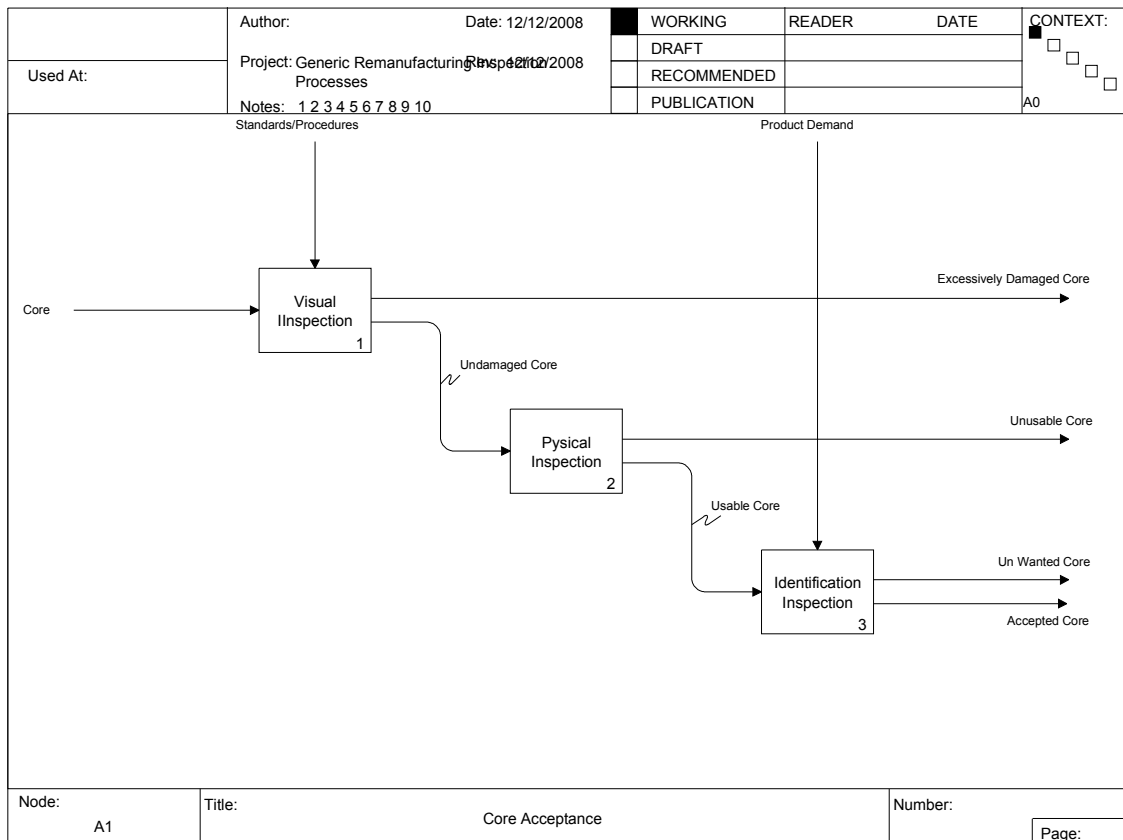
Once a compressor fails in the field it is removed by a highly skilled technician and returned to CompressorCo. The technicians are either employed by the owner of the equipment or the task is subcontracted.

All compressors that are returned in this way are either worn out or have failed during use. Cores are held in stock and when ordered are passed through the remanufacturing process. Skilled technicians then install the compressor.

The price of a remanufactured compressor is typically 50% of the cost of a new unit. For rare cores the actual unit is remanufactured and a quote for the work required is given to the customer.

Replacement parts are now sourced from OEMs as well as 3<sup>rd</sup> party producers. OEMs have not always been this cooperative. Until recently they saw 3<sup>rd</sup> party remanufacturers of their equipment as a competitor however they now compete within the spare parts supply market. In the compressor remanufacturing industry unprocessed cores are referred to as 'dead bodies'

It was commented that the major cost of remanufacturing in the compressor industry is the purchase of replacement parts. The following figure shows how CompressorCo's core inspection process differed to the Strategy I approach.



**Figure 12 - Modified Core Inspection Procedure CompressorCo**

It can be seen from Figure 12 from comparing this to the generic core inspection procedure Figure 7, that CompressorCo do not do a performance inspection prior to disassembly of the core. This was stated to be due to the fact that the value of the casing is sufficiently high that only a damaged casing would make the unit uneconomical to remanufacture. This would be consistent with strategy II feasibility based core acceptance decision however a limited number of cores may also be scrapped if there is insufficient demand. For this purpose there is an identification inspection step as well as a visual inspection. Once core

inspection has been carried out the cores will normally be held in stock until an order is received.

## **8.2 VacCo**

VacCo is a manufacturer of high vacuum pumps for business customers. The pumps are commonly used in processes such as semi conductor and solar cell manufacture. They have the capability to reduce pressures close to ultimate vacuum. They operate in a vast array of different conditions and have an initial life span of 3 months to 5 years depending on these conditions.

VacCo have been carrying out remanufacturing on their own products for over 20 years. Approximately 20% of the £5M business is currently in remanufacturing of existing pumps. Currently VacCo remanufacture 45,000 different product types, all of which they manufactured originally. Globally they process over 4000 units per month. This ranges from small gauges to multiple pump systems. VacCo operate a large number of hubs globally which carry out remanufacturing operations. Despite the fact that they are the OEM of the products they remanufacture, VacCo still state that parts are their biggest cost.

### **8.2.1 Core Acquisition**

Companies that use vacuum pumps can have up to 2000 pumps on one site. For this reason they often have highly skilled technicians who remove the pump before it is returned to VacCo. If such technicians are unavailable then pumps are removed by VacCo's own technicians. Due to cost pressures, the majority of pumps are run 'to crash' (fail or fill up of process material). Many systems run with multiple redundancy and a lot is known about when they are likely to crash. This minimises negative impacts when the pumps crash. Due

to the environments in which the pumps operate they are received in a vast array of different conditions. In some cases metal can be eroded from one part of the pump and deposited elsewhere causing it to crash.

### **8.2.2 Inspection Procedures**

On arrival at the local facility the core acceptance procedure largely follows the generic process. First of all a visual inspection is carried out in order to assess major damage. A physical inspection is carried out to identify if any parts are missing. Digital photos of the core are also taken at this point. The identification inspection is more detailed than has been observed in other processes. It is essential for safety reasons that the core that is returned is the exact core that is expected. The way a core is handled depends on the substance with which it has been working. This is specific to each individual pump. No performance inspection is carried out as such before the core is disassembled.

Once the core has been disassembled each part is judged against performance criteria to assess its suitability for reuse. By this point one third of the labour costs associated with remanufacture have been spent. This performance inspection stage has an additional purpose which is to assess any warranty claims against the product. The performance specifications against which the parts are judged are specific to the level of service required by the customer. Reconditioning is carried out on some parts in order to bring them within specification.

Once the parts have been reassembled into a product the unit undergoes a performance inspection. Once again the specifications for this differ by product and use. Some units are known to perform very badly indeed during factory testing that work as required when they



are installed and an amount of material enters them. Following final testing the units are returned to as received configuration.

During the interview it was noted that services and warrantee returns fit more closely with strategy II since the unit must be processed and returned. Where units are remanufactured to stock the process fits more closely to strategy I. Commercial returns on the other hand appear to be processed according to strategy IV where no routine disassembly is carried out. The electronic control part of the assembly, once separated from the rest of the core is processed using a strategy III approach. A visual check is made followed by a series of tests.

An interesting point made during the meeting was that customers have different expectations for how the unit should look depending on if they buy a remanufactured unit or have their existing unit processed. Casing dents that would be acceptable if it is the same product returned are unacceptable if a 'new' remanufactured product is supplied.

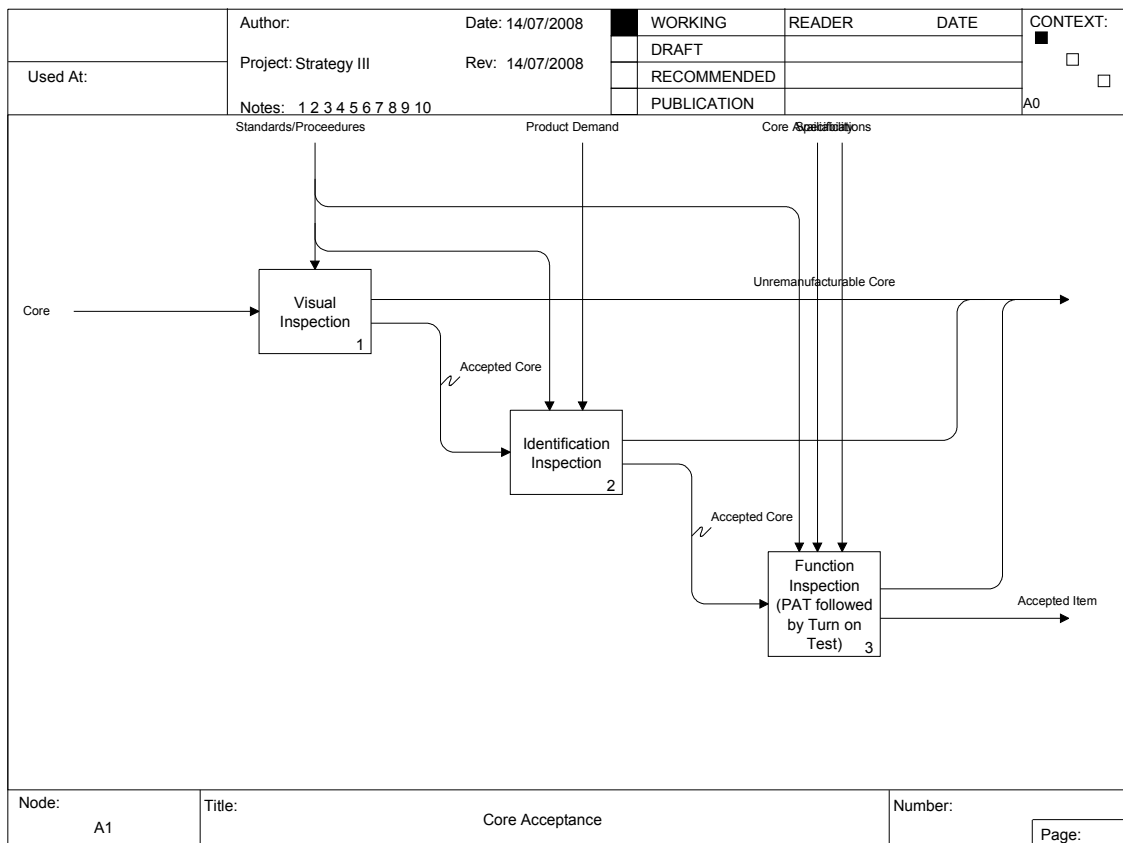
### **8.3 WasteCo**

WasteCo is a WEEE processor based the North of the UK. Their stated mission is to maximise value from waste. They are also a member of ICER the Industry Council for Electronic Equipment Recycling. They currently claim to provide the most viable form of WEEE recycling both environmentally and financially. They do this by reselling a large amount of the equipment they process and also carry out manual disassembly in order to maximise purity and in turn revenues from the recyclates they produce.

WasteCo hold contracts to treat WEEE from eight Civic Amenity (CA) sites in the local area. CA sites are run by local government and collect waste products from members of the public. WasteCo provides storage and collection equipment in order to minimise damage during the period from when the equipment is dropped at the CA site by the end user and when it arrives at their facilities. The largest volume product that WasteCo deals with currently is Cathode Ray Tube (CRT) TVs. For this reason this was the product that was studied in most detail.

As equipment is unloaded from transport containers it is sorted into two groups: items that have a positive resale value and those that are un-reusable. Items may be un-reusable if they are heavily damaged in transit or if there is no demand for them due to their age. Those which are considered un-reusable constitute the majority of items which are received. Those items which show potential for reuse are first put through a standard PAT (Portable Appliance Test) which is required by law before the equipment is put through further tests. These tests are specific to the equipment. In most cases the first step is a turn on test. Following this tests are carried out to assess the likely remaining life of the equipment as well as its full functionality.

Equipment that fails these initial stages of testing is assessed for value once working. If viable then equipment is repaired as necessary. If infeasible for repair the items are recycled using the process described above. This is in agreement with strategy III from the framework with the addition of a PAT safety test as shown in the following figure. The process shown in Figure 13 is the WasteCo equivalent of Figure 7, the generic core inspection procedure.



**Figure 13 - Modified Core Inspection Procedure WasteCo**

Once any necessary repairs have been carried out, all working equipment is either sold within the UK through WasteCo's retail operation, where it is sold with a warrantee at approximately 50% of the cost of new, or bulk shipped to countries where it has more value. All equipment is processed to order and is shipped as soon as it is available. In order to prove that the company is acting responsibly and to 'convert' waste back into products they must demonstrate that it is fully functional and safe to use.

Where ever possible parts are recovered from other equipment to facilitate repair. With equipment such as vacuum cleaners a 'many to one' remanufacturing approach is followed. Equipment of a certain type and make is left to accumulate for a period of time. Once sufficient equipment is possessed it is inspected and repaired by exchanging parts between

units. The non functional equipment that remains is disassembled and recycled. The working products are returned to the market.

Remanufacturing Strategy III is followed for this process however equipment that fails is sometimes cannibalised in order to provide parts for use in other products.

## **8.4 FlightCo**

FlightCo was established in 1955 manufacturing pins and rivets. They have been based at their present location since 1972 and currently employ 285 employees. Currently they mainly manufacture turned components for aerospace, defence and associated industrials. Some work is still done for commercial customers however quality demands from the aerospace industry make them uncompetitive in this area.

A small part of the business is the repair and overhaul of aerospace subassemblies. As aerospace component manufacture becomes more competitive the company is looking to expand its much more profitable, but currently very small, remanufacturing processes.

Cores are supplied by customers wishing them to be remanufactured. Each core must be returned to the customer that supplied it. FlightCo remanufacture other company's products as well as their own.

Before a core is disassembled a brief check is made to insure that the unit delivered is the one that was expected. Any obvious sign that would make the unit unusable is also looked for here. This only includes damage which would make the unit beyond repair.

The unit is then disassembled and each of the parts is performance inspected against certain criteria. This includes number of flying hours, viable damage and wear, measurement of diameters etc and for some parts a leak test. Once the extent of the work required is known a quote is given to the customer. Typically if this quote is less than 2/3 of the cost of a new unit then the quote will be accepted. It is only after this quote is accepted that further work is carried out. In practice it is very rare for the work not to be carried out.

Replacement parts are obtained from the component manufacturing side of the business where possible. Other parts are bought in from other companies. Approximately 20% parts require rework and other treatments before they can be reused.

Once all parts are available the core is reassembled. A test rig is used to extensively test the product before it is returned to the customer. Tests are carried out in accordance with pre approved air-worthiness release procedures. Where necessary fault finding and rework are carried out in order to bring the equipment within specification. This process matches Strategy IV in the framework shown in Figure 10.

## **8.5 RetailCo**

RetailCo is a UK based retailer which sells electronic consumables. These are often bought directly in China with RetailCo organising shipping to the UK and onward logistics. As the importer of this equipment RetailCo is responsible for its safety. Currently RetailCo sells customer returns to an agent who takes on this safety responsibility. They repair, debadge and export the equipment, once working, to countries outside the EU.

RetailCo is currently looking at the feasibility of setting up reverse logistics activities incorporating remanufacturing so that it will be able to recover more value from returned equipment. This is largely due to the large rate of returns, many of which are thought to be fully working. RetailCo does not offer warranties on its products but does have a liberal returns policy.

A similar company known to RetailCo operates such as system and the procedures discussed below are how it is anticipated that the new system will be run.

Customers return products to the store where they were purchased. These returns would be sent on a regular basis to a central returns centre.

First of all any items damaged beyond repair would be disposed of. Identification inspection would then be carried out in order to ensure all recalled and dangerous products are dealt with properly. Items of different values would be treated in different ways. Products for which there is no longer a demand may also be disposed of at this stage. Prior to a functionality or turn on test each item is PAT safety tested. They are also tested against hygiene standards. If small items, such as kettles, fail this test then they will be scrapped after the faults are reported to the manufacturer. Any working small appliances will be reboxed and sold in RetailCo's stores. This process matches Strategy II in the framework shown in Figure 10.

Larger, more valuable equipment, such as LCD TVs, will always be repaired if it is feasible due to their high value. In the case of an LCD TV, if the screen is undamaged then the repair will always be cost effective. Once any necessary repairs have been carried out the

unit will undergo final testing before being reboxed and sold in RetailCo's stores. This is the same as Strategy IV in the framework.

## **8.6 TonerCo**

TonerCo is a remanufacturer of laser printer toner cartridges based in the south of England. Cores are purchased by TonerCo from core brokers.

Cartridges are inspected at core level. If the casing of the cores is damaged then they are rejected. Cores are also rejected if they are not either OEM or remanufacture by TonerCo. This is due to the fact that the quality of the components used to remanufacture the cartridge is not known. Cores for which there is no current demand are either put into stock or rejected and recycled. In total 90% of cores received are remanufactured. A print test is carried out on the cartridge. If it is found to work then the cartridge is disassembled. If it does not work then fault finding is undertaken before disassembly.

Once disassembled the components are inspected for damage and tested against specification. It is known how many times OEM parts can be reused before they fail. It is also known how many times parts supplied to TonerCo can be reused. This information is used to determine which parts should be replaced before the cartridge is reassembled. If required cartridges can be upgraded during this process for example to hold more toner.

After reassembly the cartridge is tested in a printer before it is repackaged and made available for sale. TonerCo experiences a return rate of its remanufactured cartridges of approximately 1%. This process matches Strategy I in the framework shown in Figure 10.

## **8.7 ClothesCo**

The stated mission of ClothesCo is to divert textiles from becoming waste by making them into individual, bespoke and fashionable items. In order to do this the business makes its own clothes for resale, from discarded fabric and clothes, but also runs workshops training others how to do it. These notes do not cover the workshop side of the business. The clothes are sold through many outlets including market stalls, festivals, workshops, websites and shops. Some of these are operated by ClothesCo whereas others are not.

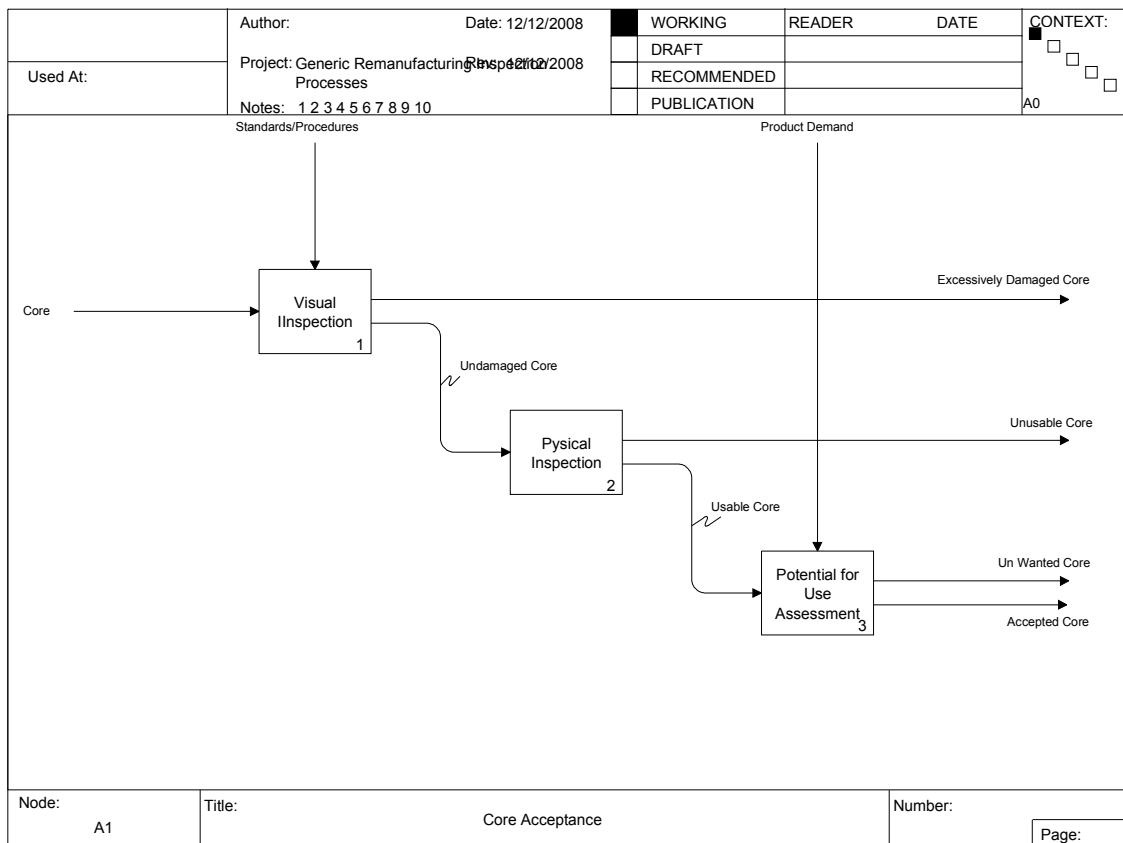
Unwanted textiles are donated to ClothesCo directly from the public. Their location in a university town means they receive donations at specific times of year. They also source materials from charity shops and other locations. Purchases from charity shops are based on specific needs whereas donations are often unsolicited but nonetheless very useful. The input material consists of curtains and unused fabric as well as complete clothing. Some clothing is stored in the anticipation that it will become fashionable again whereas other clothing is repurposed as follows.

Core level inspection is largely done by eye and experience. Materials that are used are assessed for quality, feel and other characteristics. As one of the stated aims of the organisation is to minimise textile waste the amount discarded at this point is very low indeed. It may also be the case that a customer requires a specific piece of clothing to be used. Following the physical assessment of the materials, the potential for use is assessed. There is no formal process for this but it relates to how well items made from similar designs and materials have sold in the past.



Textiles are cut, shaped and sewn into a new garment. Additional new material is used for zips and fasteners etc to ensure longevity. There is no formal inspection stage during this process however attention is paid during sewing to ensure materials are of sufficient quality. Once the clothes have been made, newly conceived items are worn by staff for a period of time in order to ensure durability. Those that fail these tests are rethought or reworked into different items. Those that pass are made available for sale using the routes described above. ClothesCo appears to operate using a combination of the strategies described in Chapter 6. The items are not remanufactured as such but more cannibalised and made into new items. Although the new item may still take the form of the old item one example being three leather jackets formed into one, the identity of the new item is not the same and therefore the process is not remanufacture.

The following figure shows the core inspection procedure operated by ClothesCo and replaces the generic core inspection procedure shown in Figure 7.

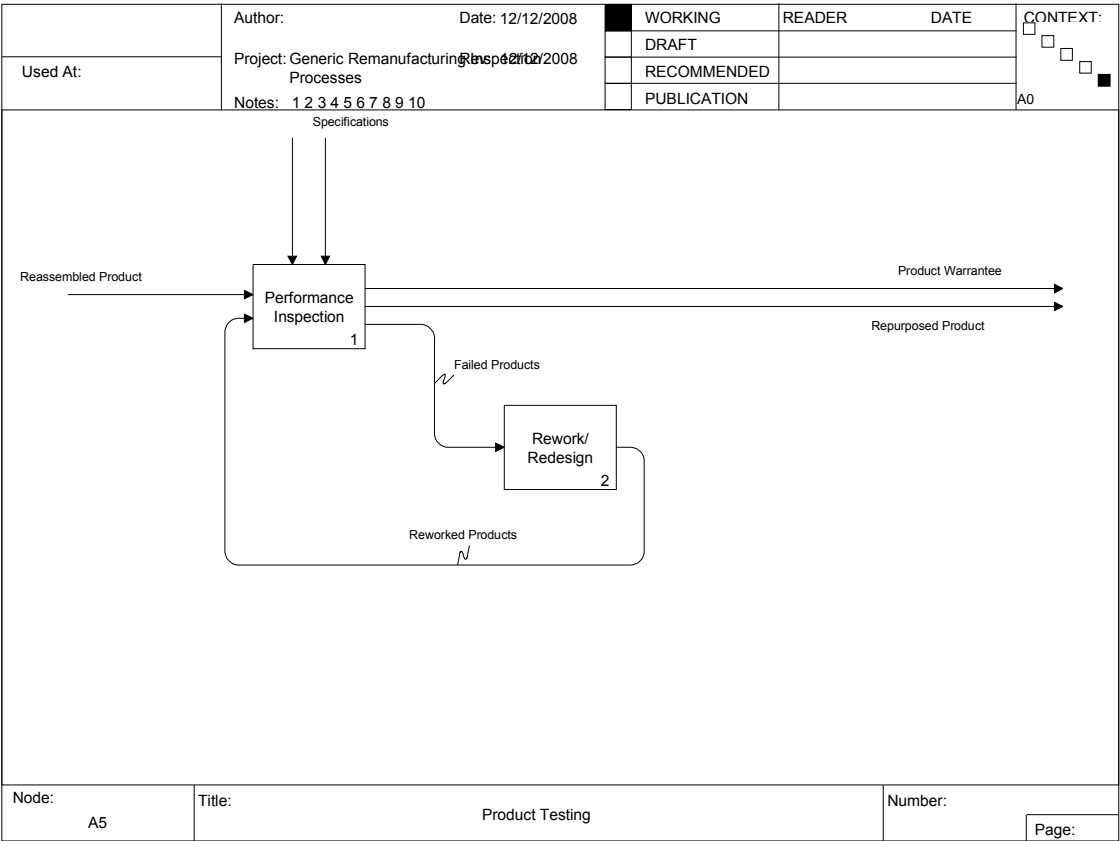


**Figure 14 - Modified Core Inspection Procedure ClothesCo**

It can be seen from the diagram that the inspection process is primary concerned with the state of the core as with other remanufacturing procedures. The following process, where demand is normally estimated, is more difficult since it is likely that the core will be reassembled for something that is a one off and has not been sold before. This makes the process more about how it can be used rather than the demand for the item itself.

The interviewee agreed that part level inspection procedures probably matched what is done in Strategy I but was unsure due to the nature of their process. Parts were reportedly tested and reworked using an informal process during reassembly.

The following figure shows the final testing process used at the company which is the equivalent of the generic final product testing procedure shown in Figure 9.



**Figure 15 - Modified Final Product Inspection Procedure ClothesCo**

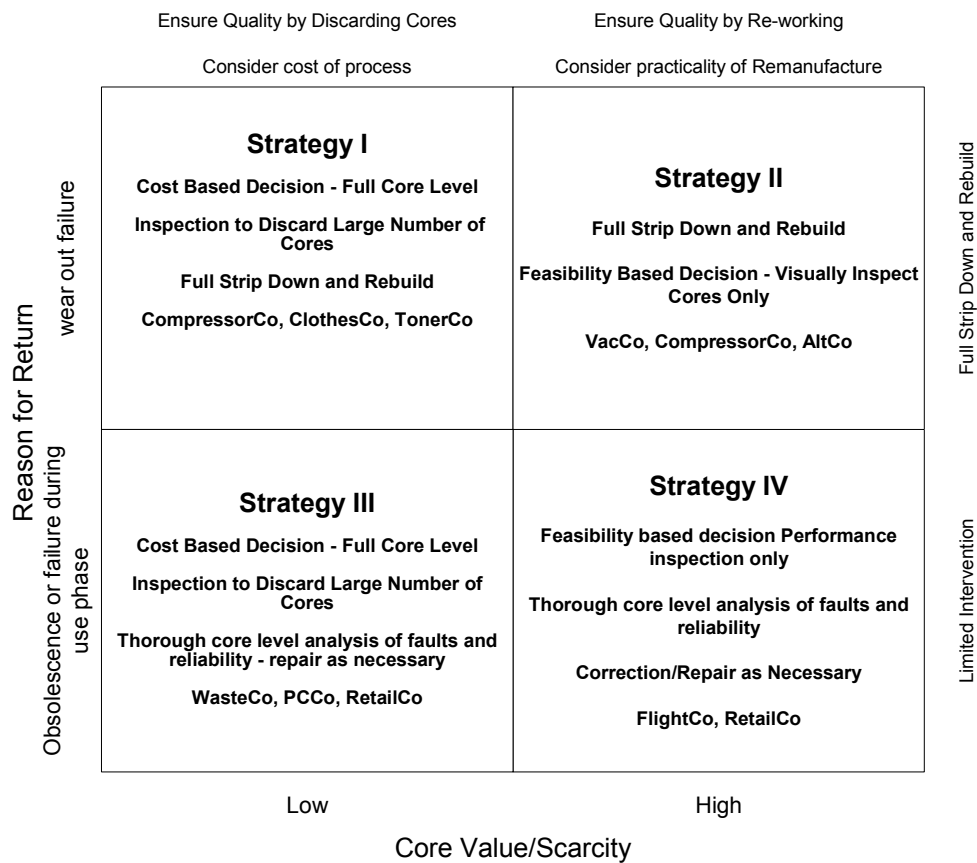
It can be seen that as well as rework operations to fix errors during remanufacture, “rethinking” operations are also carried out in order to correct errors in the design of the product. The aim of these is to correct mistakes caused by the use of inadequate materials or fixing methods.

ClothesCo is based in what is ultimately the most fashion conscious industry. This is not a common place for remanufacturing companies to be found. Items that are produced are fundamentally different to the items that are used and command much higher prices. It is

often the intention of the design to make clear that the item has been made from old textiles. Examples of this include shorts and skirts made from cartoon character printed bed sheets and a leather jacket made from a leather sofa. The fact that they are made from old textiles adds to the value in itself. The phrase repurposing would appear to fit more closely to the description of this process than remanufacturing. The process fails to fit neatly within the model that has been developed.

## **8.8 Case Description Summary**

This section has described the inspection processes of the companies which were used for the validation stage of this research. They represent a wide variety of industries and have shown general agreement with the framework and process models that were presented in Chapter 6. The following figure shows the framework and how the validation cases fitted into it.



**Figure 16 - Framework Showing Validation Cases**

It can be seen that the cases studied for validation fitted well with the proposed framework. Some of the cases operated their inspection processes in different ways depending on the product that was being remanufactured. CompressorCo was seen to operate using Strategy I for cores with high availability and Strategy II for cores with low availability. RetailCo planned to use Strategy III for items with low value, where the cost of repair is likely to quickly exceed the value of the item, and Strategy IV for items with high value where the cost of repair is almost always less than the value of the item. The inspection processes used by ClothesCo were seen to fit with Strategy I however their stated aim to reduce waste to landfill means that they do not discard large amounts of material.

The following section of this chapter will analyse their thoughts about the relevance of the research which were collected using the questionnaire developed in the previous section.

## 8.9 Relevance of the Research –Questionnaire Responses

Data was collected from the case study interviewees using the questionnaire developed in the previous chapter. This section discusses the responses to each of the questions relating to Thomas and Tymon (1982)’s necessary properties of relevant research. The following table shows a summary of responses on a Likert Scale. Responses to negatively phrased questions have been inverted. Therefore all of the results below are on a scale of 1-6 where 6 indicates strongly agrees with the statements and 1 indicates the respondent strongly disagrees with the statements. Where multiple questions were asked to address the same construct mean values were calculated and are shown in the table below. A detailed table of responses can be found in Appendix L.

Company	Descriptive Relevance	Goal Relevance	Operational Validity	Non-Obviousness	Timeliness
VacCo	6	3.3	5	4.3	4
WEEECo / WasteCo	5	2.0	5	4.0	2
RetailCo	-	6.0	5	5.0	5
RetailCo	-	6.0	5	5.0	5
CompressorCo	5	3.5	5	2.7	3
FlightCo	4	4.0	6	4.3	3.5
TonorCo	5	3.5	2	4.3	4
GearCo	5	4.3	5	3.0	2
AltCo	5	3.0	6	4.0	2
ClothesCo	2	3.5	6	6.0	1

**Table 11 - Validation Questionnaire Responses**

The remainder of this chapter will discuss the results given in Table 11 and will use these to argue that the model and framework that were developed are both useful and relevant to remanufacturers. It will do this by discussing the responses to each of Thomas and Tymon (1982)’s five necessary properties of relevant research which were discussed in section 7.2.

## **8.10 Descriptive Relevance**

All respondents agreed that the models that were described in the meeting closely matched what is done with their processes. 1 case strongly agreed, 5 agreed and 1 case slightly agreed. ClothesCo disagreed, it is thought that the lack of agreement with the model is due to the fact that, in the case of ClothesCo the product is not the same as the core which is used. Effectively they run a repurposing business rather than true remanufacturing. RetailCo failed to answer the question for the above mentioned reason.

With an average response of 4.6 including the response from ClothesCo it can be said that the research is descriptively relevant. Removing the ClothesCo response gives an average response of 5.

## **8.11 Goal Relevance**

The responses to questions in this category were more mixed. In general the companies slightly disagreed that inspection costs them a lot of money with almost all respondents stating that parts were their major cost. This is an interesting response since the amount of replacement parts required is a direct result of how many are discarded which is decided using inspection procedures.

In the interview with VacCo it was stated that their facilities in different parts of the world remanufactured the same equipment but with varying degrees of profitability. This was due to excessive replacement of parts in some areas. In some of their facilities, VacCo employees are worried about the impact of failure and so replace more parts than in some of their other facilities. Inspection is used to gain confidence that a part will perform as expected. Formalised inspection procedures would give rigid rules that could remove some

of this variation. It would also help workers to share knowledge about what degree of wear or damage is acceptable for different products operating in different environments.

Only TonerCo agreed that inspection costs were a large impact on their business. This is thought to be due to the fact that Toner remanufacturing is a very low margin competitive business. The process of remanufacturing the cartridges themselves is relatively straightforward and parts are widely available from third party remanufacturers which in turn reduces this burden on the company.

The second question aimed at assessing the goal relevance of this research asked if the interviewee agreed that inspection requires highly specialised skills. There was an interesting difference of opinion with this question. One respondent stated that knowledge was the important factor and not necessarily just skills. In general this question was met with a positive response. WasteCo, however, disagreed with the statement. It was thought that this might be due to their exceptionally high core discard rate. With rates of 80-85% they use very simple techniques to discard potentially unsuitable cores. They do this based on age of unit, obvious damage and potential for resale once working.

TonerCo and AltCo also slightly disagreed with this statement. These are both very well established industries with large throughput and very well documented procedures. It is thought that this would account for the companies' removal of skill from their processes. All of the remaining companies agreed that highly specialised skills were required for inspection processes. In general those companies that agreed that highly specialised skills were required for inspection also agreed that the skills were currently in a shortage.



Overall the goal of this research appears to be relevant to the companies that were interviewed. Companies that have well established processes require less-skilled employees to carry out inspection. Companies with lower volume of cores required more highly-skilled inspectors. This research appears to be more relevant to those companies with less well established visual inspection type methods. In the survey cases do not agree that the act of inspection costs them a large amount of money. A discussion about why this may have been the case follows in the summary.

### **8.12 Operational Validity**

All companies with the exception of TonerCo agreed or strongly agreed that they were allowed to modify the inspection procedures within their process. The reason that TonerCo disagreed is not known.

Since companies are able to modify their inspection procedures in all but one of the cases studied it can be concluded that the research is operationally valid.

### **8.13 Non-Obviousness**

Three questions were used to assess the non-obviousness of the models developed in the research. All but one of the interviewees, GearCo, agreed that the model assists their understanding of inspection processes. The responses ranged from slightly agree to strongly agree with an average of 4.6. Only one of the interviewees agreed strongly that the model assisted their understanding of inspection. During the interview it was stated that inspection was something ClothesCo was interested to carry out more formally.

In response to the question that the model would help the interviewee to explain the purpose of inspection procedures to their colleagues and those new to their organisation the response was also very positive with an average of 4.4. GearCo again disagreed that the model would be useful to them. In addition to this CompressorCo disagreed strongly that the model would help them. This is a surprising result given the interviewee's response to the previous question. It is thought that due to her vast experience of the industry and the maturity of the industry itself she felt she required no additional help.

The third and final question asked to assess the non-obviousness of the research was based around the likelihood that the interviewee would use the models in order to make improvements to their process. Half of the respondents stated that they disagreed slightly that the model would help them to make improvements to their process. CompressorCo once again disagreed that the model would be helpful. The other half of the respondents responded positively, indicating that the model would help them to improve their process. The most positive responses were from ClothesCo and RetailCo. During interviews it was made clear that these companies had a current interest in modifying or establishing their inspection procedures.

Overall it appears that the research is regarded as non-obvious by those interviewed. Almost all respondents stated that it assisted their understanding of inspection and that they plan to use it to educate others. Those relatively new to the area of remanufacturing with less well established processes believe that it will help them to make improvements to their processes.

### **8.14 Timeliness**

Interviewees were asked if they were currently facing problems with inspection. The response to this question was split and polarised. Four of the responding companies stated that they agreed with this statement. The remaining companies disagreed with two companies disagreeing strongly.

Companies were also asked if they had a current shortage of inspection skills. The response to this question was once again split and polarised. Four cases agreed that they were currently facing shortages. The remaining cases all disagreed, one strongly and two slightly.

Of the companies interviewed, some see inspection as a very important area with which they are currently facing problems and a skills shortage. Others do not see the problem as being an issue for them at the moment. Companies which have not been engaged in remanufacturing for long and those new to the area considered the research to be more timely than those who have mature processes.

### **8.15 Summary**

A survey tool was used to assess the relevance of the model which was developed in this research. Analysis was carried out using Thomas and Tymon (1982) five necessary properties of relevant research. The research was presented to each respondent individually. Following this they were asked to complete a questionnaire.

The research was found to be descriptively relevant. All companies agreed in the questionnaire that the models closely matched their processes. All interviewees

successfully located their companies on the model. Where processes differed (eg for commercial returns) an explanation was given as to why.

The goal of the research was found to be partially relevant. The companies that face the most problems with inspection are those processing small numbers of products and those new to remanufacturing. All but one of the companies interviewed confirm that the research is operationally valid by stating that they are able to modify the processes of their company.

In general the individuals that were interviewed stated that they found the research aided their understanding of inspection and would be helpful to explain their processes to others. Only those companies new to remanufacturing feel that they will be able to use the model to improve their processes. This is a good result as it shows how the models can be used as an aid to processes design. Those who have been competing successfully for several decades in the remanufacturing industry are confident that their processes cannot be improved. Approximately half of the companies feel that the research is relevant to the problems they are currently facing.

The respondents did not agree that inspection currently costs them a lot of money however on further questioning they did agree that replacement parts did. In hindsight this could have been confirmed through the use of an additional question to address this important question.

Overall it can be said that the research is relevant to the operations management community. It is the case that companies new to remanufacturing find the research more relevant than those who are very well established.

## **CHAPTER 9: DISCUSSION**

This chapter will add the new cases which were discussed in the previous chapter to the framework developed during the early stages of this research. An important part of the validation meetings was to ask the interviewee to locate their process on the remanufacturing framework shown in Figure 10. Data was also collected about the number of units processed per month, whether their process included full disassembly as well as other key data. This enables the case to be located on the framework by the researcher as well as the interviewee. Following this a discussion was made with each interviewee about why they thought their company should be positioned where it was on the framework.

In Section 3.5 it was stated that this research would attempt to answer the following questions:

- 1) It appears that there are differences in the inspection processes carried out by the three cases described in Chapter 2: Are all processes different or are these differences part of a pattern of different strategies?
- 2) Assuming these differences are due to different strategies, what are the company or product characteristics which affect the choice of remanufacturing strategy?
- 3) What knowledge and skills are required for the effective management of a remanufacturing process using each of these strategies?

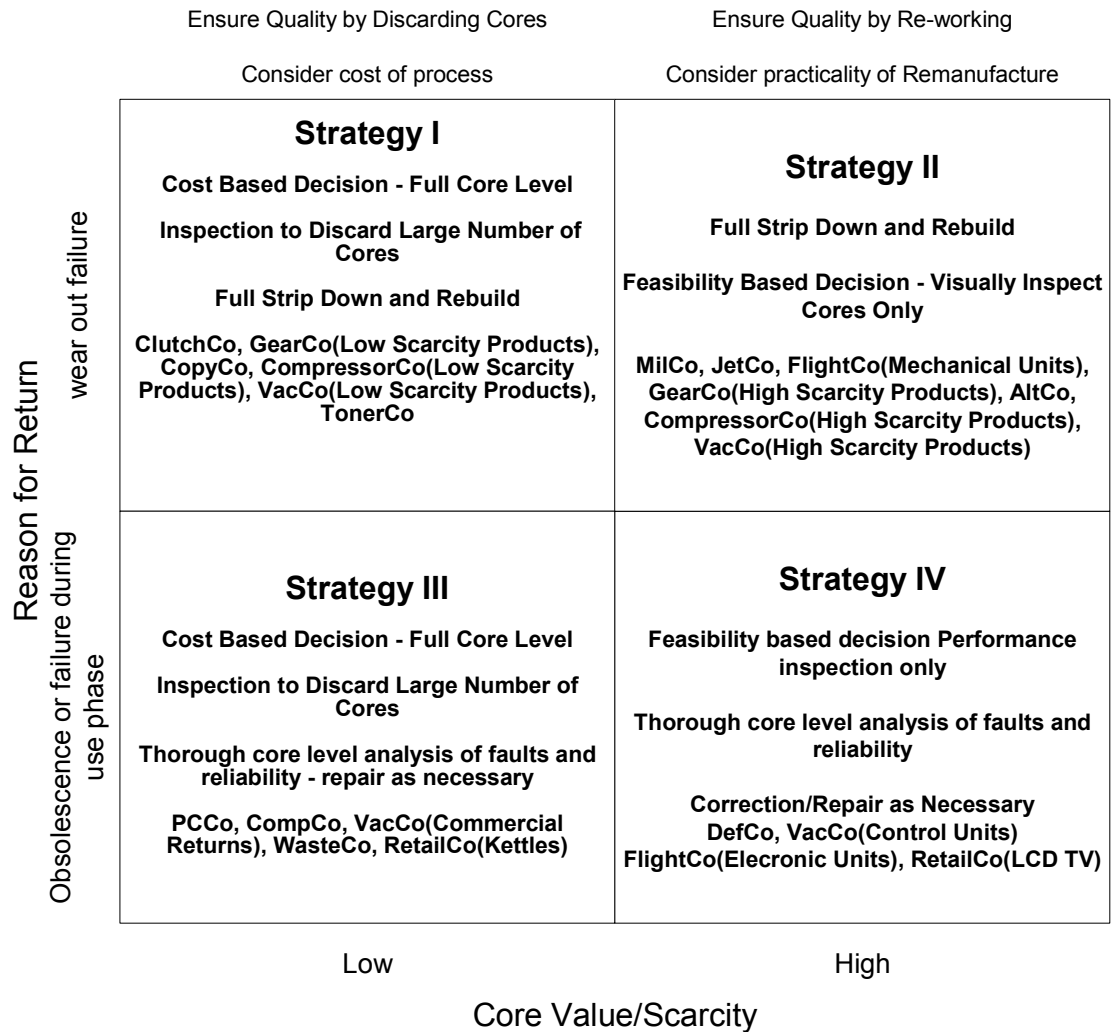
This chapter will discuss how each of these questions has been addressed. A discussion of the findings to questions 1 and 2 can be found in section 9.1 a discussion of the findings related to question 3 can be found in section 9.2.

## **9.1 Were there strategic differences between the cases observed?**

The differences in remanufacturing processes, that were discussed in section 3.5, were found to be part of a pattern of different strategies for remanufacturing. It has been proposed that these are due to two main product characteristics. There are core value and the reason for return of core. The following section outlines these differences and discusses the framework for remanufacturing strategies that has been produced to demonstrate explain the theory.

### *9.1.1 Final Framework*

In total sixteen companies were interviewed in the course of this research. In the following diagram each case has been put on the model developed in the course of this project.



**Figure 17 - Populated Framework of Remanufacturing Strategies**

It can be seen that there are a number of companies that feature in more than one category in the diagram above. This is due to the fact that the variables are specific to a given product in a given state rather than it being a company decision. It is beyond the scope of this research to discuss access the relative merits of the ‘horses for courses approach’ as opposed to the ‘bang bang’ approach described by Richter (1997). It is, however, thought that it is likely that this is a factor of volume, value and risk. With large volumes it may be easier to put all of the returns through the same process. This is of course necessary if the condition of each unit is not known. The following section will discuss each of the

strategies in more detail and will note any major differences to it from the cases that were studied. Due to their large number the full set of IDEF0 diagrams of the strategies have not been included in the main text but can be found in Appendix H.

### *9.1.2 Strategy I*

A cost based decision is used to identify the most economical cores for remanufacturing. A large part of this is an assessment of the amount of work required to process the core. This is done through simple tasks such as testing to see if relevant parts move smoothly. This assessment was described by a core broker as ‘scratch and sniff’. It gives a very quick estimation of whether the core is likely to be economical to remanufacture and is very effective. The same respondent stated that only 5% of the cores that passed this test were discarded during the next stage of inspection showing that in some cases this can be a very effective method indeed. Once accepted, cores are fully disassembled and parts are inspected. All cores, regardless of condition or reason for return, are processed in the same way. This is usually a high volume process where accurate estimates of the remanufacturing cost must be made with very little information. The profit in this type of strategy is optimised through quick acceptance of cores that will be low cost to remanufacture and quick rejection of cores that will be expensive to remanufacture.

### *9.1.3 Strategy II*

When cores are scarce, or the same individual core must be returned to a customer, less emphasis is put on core level inspection. The aim of the core level inspection process is to establish if it is possible to remanufacture a given core rather than how economical it is. This is either because the unit has very high value, due to its scarcity, the fact that it must be returned to the customer or that it is impossible to source a replacement. Prior to



disassembly cores are only discarded if they have major damage which would make them very difficult or impossible to remanufacture.

Following this, cores are disassembled, an assessment of how much work is required is made and a quote is given to the customer. If a customer rejects this quote and the core is returned to the customer this can create a significant loss for the business. VacCo stated that by this point one third of its labour costs had already been sunk into the core. In practice these quotes are usually accepted.

It is sometimes the case that an individual core within a batch for a single client will be remanufactured at a loss if that means the maximum lead time for a given contract is not exceeded. A new unit may also be supplied in some cases if the remanufacturer considers the client a valuable customer. Once a quote for remanufacturing has been accepted the part level and finished product level processes are identical to that for Strategy I.

The ability to accurately assess the faults of a system and to accurately provide quotations is key to this system. Knowledge of the customers needs and other options must be held to ensure quotes are reasonable and not rejected. It must also be known what would make a given product infeasible or very expensive to remanufacture.

#### *9.1.4 Strategy III*

This strategy relies heavily on discarding unsuitable cores in large numbers at the earliest possible stage. Cores that are un-sellable once processed perhaps due to their age and/or demand will be rejected immediately. Borderline cases that do not pass a turn on test will also be discarded. Only those cores with high value fail the turn on test are analysed further.

Faults are identified and those that are deemed economical to repair are processed. Disassembly is only carried out to the level required to replace the failed component or components. Cores are not worn out and are not routinely disassembled. Final product testing is used to assure the company that the product will function for a full second life. Market knowledge and valuation of products once repaired is key to the success of this strategy. To repair products for which there is no market would soon cause the end of a business operating using this strategy.

Core faults must be quickly and accurately identified to facilitate quick core discarding decision making.

#### *9.1.5 Strategy IV*

As with Strategy II the main aim here is to assess the feasibility of the remanufacturing of a given core. Less emphasis is put on some of the inspection procedures however the performance inspection is critical for finding the faults with an item and in most cases providing a quote to the customer for the work. As with strategy III disassembly is only carried out in order to facilitate the replacement of failed components and final product testing is used to ensure the product will function for a full second life.

As with strategy II the major knowledge which is required with this strategy is the other options available to their customers. Companies must ensure that their quotes are accurate and acceptable to their customers otherwise they could lose capital invested into the inspection of the core. As with Strategy III accurate fault identification is key to the success of this strategy.

#### *9.1.6 Cases with Apparent Multiple Strategies*

It can be seen that some companies place themselves in more than one strategy group. This is not because they are unsure about where they fit but due to the fact that they use different strategies for different products, in the case of RetailCo, and different strategies for different reasons for return in the case of VacCo.

RetailCo gave two very different examples of products which it plans to remanufacture, one being very low value and one very high. In the case of very low value items such as kettles, very little time needs to be invested into the unit before it is unviable to repair it and it makes a loss. This fits with Strategy III. For this reason almost all of the items that fail a safety and/or turn on test are discarded. In contrast RetailCo also plans to remanufacture high value LCD TVs. It is known that any repair other than screen replacement can be carried out economically. The only reason RetailCo would discard such an item is if it was completely destroyed. This product fits into Strategy IV on the framework.

The case of VacCo gave an interesting insight into the different ways the same product can be treated depending on its source. VacCo stated that they had processes for different returns that matched with each of the strategies in the model. Returned items for which there was no current customer were treated using Strategy I, while Strategy II was used to process equipment that had been supplied by a customer that must be returned to that customer. Commercial returns were processed using Strategy III, they were quickly inspected to ensure function and were reboxed and made available for sale. Finally customers that returned items due to a fault with the electronic control mechanism were treated using Strategy IV.

It was found that remanufacturing strategy appears to be dictated by a combination of a number of factors; the value & nature of the product as well as its functional state and the needs of the customer. This is particularly relevant if the ownership of the item stays with the customer while their item is remanufactured. In these cases customers expect the same unit to be sent back to them as they supplied. This is almost always economical and is almost always done. During discussions with other cases it was found that similar behaviour was carried out. For example ClutchCo was found to not hold stock of very slow moving parts, for example clutches from classic vehicles, they do however have the skills and necessary equipment to be able to remanufacture them. They carry out a Strategy II process with these items and bill the customer based on the work required in a similar way to the cases which work primarily for the ministry of defence.

#### *9.1.7 The Outlying Case - ClothesCo*

One case that was studied failed to fit any of the strategies exactly. Some aspects of Strategy IV and III were coupled with aspects of Strategy I. The key differences were observed as being as follows:

- Core ‘demand’ is driven by what the item can be used for. The creative design process is what defines exactly which cores have value. (Otherwise similar to Strategy I core level inspection)
- Items are disassembled however no formal part level inspection takes place. (No part level inspection is observed in Strategy IV)
- Product level inspection and testing is carried out as in all other strategies. One key difference is that products are “rethought”. The design and perhaps materials used are changed rather than a simple rework operation where only the failing parts would be replaced.

It is possible that these differences are due to the fact that their process could be described as a repurposing activity rather than remanufacturing. The clothes which are made bear no resemblance to the clothes which are used to make them. For this reason it is difficult to assess the cost which can be charged for each item. There is simply a price that a customer is willing to pay for a bespoke item.

Another reason for the differences could be due to the way ClothesCo procures its materials. Buying materials for a given project from charity shops enables it to carry out core selection before procuring the materials, once again reducing waste. It could also be due to the fact that the stated aim of the organisation is to reduce the amount of clothing going to landfill rather than just to generate capital.

Some materials are purchased from charity shops to satisfy a specific need. If the charity shop is thought of as fulfilling the role of a core broker then it would make sense that less emphasis is put on inspection in this stage of the process. With most materials being used it makes it difficult to identify the 'core' as such. The process resembles a many to one remanufacturing operation with no part level inspection. It is probable that no part level inspection is required due to the fact that all of the materials can be accessed while the unit is whole.

In summary, core level inspection is carried out extensively at ClothesCo. The aim of this is more to find a use for a given item of clothing rather than to decide to keep it or not. There is no hard and fast rule for costing clothing that is made. Bespoke items are sold for what a buyer is willing to pay since the buyer is unable to buy the same item elsewhere. The cost and the knowledge of which products are easy to sell is primarily based on experiential

knowledge. The following table shows the key skills and knowledge that make ClothesCo successful.

	Key Skill	Key Knowledge
<b>Strategy X</b>	Identification of what can be done with item. Potential for remake.	Valuation of Finished Products. Estimate what customer will pay.

**Table 12 - Strategy X Knowledge and Skills**

It can be seen that these factors are difficult to quantify. It is the tacit experiential knowledge that the directors of ClothesCo hold that makes their business successful. Knowing what their customers might like and would be willing to pay is critical for running their operation as it is in the other cases that were studied however ClothesCo has no option but to make to stock as its items are bespoke and individual.

## **9.2 Knowledge and Skills Required for Effective Remanufacturing**

Research question 3, as outlined in section 3.5, asked what knowledge and skills are required for the effective management of a remanufacturing process using each of the remanufacturing strategies in described in the following section. This section will reflect on this question firstly by comparing remanufacturing inspection with forward manufacturing inspection, by describing the methods used and finally by discussing the skills and knowledge required for each of the remanufacturing strategies identified.

### *9.2.1 Inspection Types*

A discussion has been made in Section 5.3 that inspection in remanufacturing processes can be carried out at three distinct stages during the remanufacturing process. These are on the core before it is disassembled, on the parts following disassembly and finally on the

product before it is made available for use by the customer. This shows similarities with the three key types of inspection in forward manufacturing outlined by Winchell (1996) and the stages described by Shewhart (1931). Winchell (1996) and Shewhart (1931) both explain that inspection is carried out on incoming materials and final products as well as being carried out during the process itself. In remanufacturing situations it has been observed that inspection is almost always carried out on the materials, in this case cores, entering the process as well as final products. In-process inspection is carried out in strategy I and II processes through the inspection of all parts of the core. However it is carried out through diagnostic testing in the case of strategy III and IV processes.

During the literature review in Section 3.1.1 it was noted that Winchell (1996) believes it is not always necessary to carry out inspection on feedstock materials. This was observed in remanufacturing where remanufacturers relied solely on core brokers such as CoreCo to supply their cores for remanufacture.

### *9.2.2 Methods used for Inspection*

The methods used for inspection were typically found to be as described by Steinhilper (1998). That is, they included visual checks and measurement often using small hand tools but sometimes using specialist testing equipment. Such testing equipment was used for the majority of final product testing.

Some of the remanufacturing processes that were studied used one stage reassembly processes. One operative was responsible for the reassembly on a single item. If any defect was found with the item then it was their responsibility to carry out rework. This could be thought of as the 'self-inspection' described by Shingo (1986). Since one single operator is

responsible for the item then it would seem unlikely that they would deliberately allow defects to occur thus avoiding the problem of operators compromising on quality as highlighted by Shingo (1986).

The strategies of all of the remanufacturing case studies show two distinct types of activity, which could be termed ‘disposal’ and ‘confidence building’ processes.

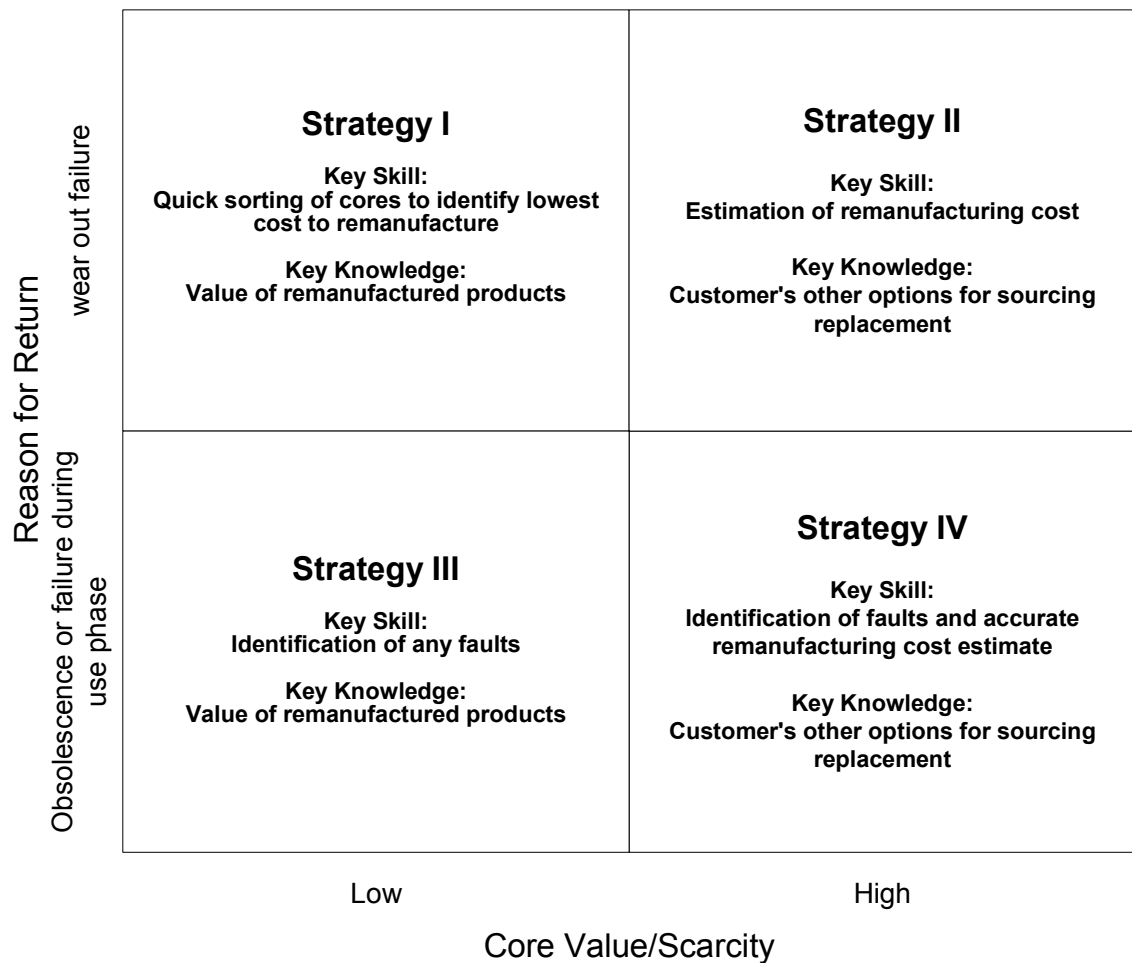
In the research it has been observed that *Disposal* activities have the effect of removing from processing any items, whether cores or components, whose performance reliability is below a certain level and which would therefore reduce the reliability of a population of products.

It has also been seen that *Confidence Building* activities are required to gain confidence that all the individual items within the population will perform as required.

### 9.2.3 *Key Knowledge and Skills Summary*

The table, which follows, shows the key knowledge and skills that appeared to be important for each of the different remanufacturing strategies.





**Figure 18 - Key Business Skills Required by Remanufacturers**

All strategies have some aspects in common, for example, value is a key factor. With any strategy the remanufacturer must have an idea of the market value of its product. This may be known as with MOD cases, cost must be <60% of the cost of new. Or they may be more intangible and based on previous sale prices. Remanufacturing products which cannot be sold at a profit is wasteful however so is inspecting products if the customer is unlikely to bear the cost of remanufacturing following quotation. An important factor of cost based decision making such as this is the method used to cost production. If this is inaccurate then

it could lead to the wrong process decisions being made. The following section will address some of the issues around costing and cost reduction in remanufacturing processes.

### **9.3 Process and Inspection Costing**

Some companies that were interviewed in the course of this research stated that they used processing costs to make core disposition decisions. These included RetailCo, PCCo, WasteCo and MilCo. Correct estimation of market price has been outlined as being key knowledge for these companies however it is important that they also correctly calculate their cost of production of a given product. Goldberg (2000) states that the most appropriate method for costing remanufacturing processes is Activity Based Costing. This is where costs are allocated to a product based on its use of resources. MilCo uses expensive high tech equipment at the same facilities as it carries out remanufacturing. According to Drury (1994) if an inappropriate costing method is used this can lead to expensive hourly labour rates. Since remanufacturing is often labour intensive this has the potential to make it appear expensive and incorrect disposition decisions can be made.

#### *9.3.1 Inspection Cost Reduction Methods*

It was found that there was a large amount of repetition within the remanufacturing inspection processes. It is reported by Brent and Steinhilper (2004) that it is necessary to carry out 100% final product inspection during remanufacturing processes. This appears to be what is done in all of the cases that were studied. It is thought, however, that inspecting cores and parts as well as the finished products may be excessive in some cases.

The following table gives a summary of the different methods that have been observed aimed at reducing the costs of inspection within their process.

<b>Technique</b>	<b>Observed in</b>	<b>Reason it Works</b>
Limited Core Inspection	MilCo	All cores must be used if feasible
No Core Inspection	ClutchCo	Adequate spare capacity and Use of Core Broker – cost of processing cores that should have been scrapped is not significant when compared with cost of inspection
No Part Inspection	PCCo/CompCo/DefCo	Electronic products unlikely to be worn out
No Product Inspection	ClutchCo	Parts Okay/Unlikely to damage during reassembly
Limited Core Inspection	CompCo	Mainly High Quality Functional Cores Received
Automate Inspection/Testing	PCCo	Product receptive to technique
Sample Product Inspection	None Observed	Used in new manufacture, same scenario after part inspection Dodge and Romig (1959)
Use of information to access reliability	None Observed	Information gathered during testing could be provided by previous user or 'green port' Gupta (1999)

**Table 13 - Summary of Different Approaches to Inspection**

This section has discussed some important comparisons between the case studies. It shows that companies processing the same equipment can cope with the same problems using very different methods. Other companies have removed parts of their inspection procedures either by effectively subcontracting them to a core broker or by removing them altogether at the potential sacrifice of an increased amount of rework. Remanufacturers want to ensure the products they sell meet the reliability requirements of their customers. This has led to a large number of inspection procedures during the remanufacturing process. The automotive remanufacturing industry states lack of skills for inspection as one of its major problems. In the case of ClutchCo, part level inspection and testing is deemed to be sufficient to guarantee the reliability of the product.

### 9.3.2 *Cost of Inspection*

It was shown in the validation findings in Section 8.11 that cost of inspection was something which did not concern respondents. This was a surprising result since the high cost of inspection, using traditional inspection techniques in forward manufacturing, is highlighted by Dale (1999) and Shingo (1986) as being the main reason for the common use of sampling inspection techniques.

What follows is a discussion of the relative merits of removing inspection stages within the remanufacturing process. These thoughts are based on the inspection cost/benefit analysis calculations outlined by Deming (2000) and described in Section 3.1.2.

<b>Inspection Stage</b>	<b>Warranty Cost</b>	<b>Cost of Processing Faulty Items</b>	<b>Inspection Cost</b>
All	Low	Low	High
Core + Part	Medium	Low	Medium
Part + Product	Low	Medium	Medium
Core + Product	Low	Medium	Medium
Core only	High	Low	Low
Part only	Medium	Medium	Low
Product only	Low	High	Low

**Table 14 - Costs/Benefits of Inspection in Remanufacturing**

It can be seen from Table 14 that removing inspection stages from the remanufacturing process would lead to savings in the cost of inspection but may lead to higher overall process and/or warranty costs.

One stage of inspection could be sufficient in some remanufacturing processes, however as described by Deming (2000), removing inspection stages in remanufacturing as with

forward manufacturing will always require a careful balance to be made between the cost of the inspection itself and the cost of processing defective items.

Removing all inspections other than at a core level would mean that there would be a likely increase of faulty products that would reach the customer. This would cause warranty costs to increase and is likely to lead to customer dissatisfaction.

Removing all inspections other than at the part level would mean that there would be a reduction in these warranty costs. On the down side more unsuitable cores would be disassembled giving wasted time and effort. Customers may still receive faulty goods however the faults would be likely to be lower in number than the previous example.

Removing all inspections other than at a final product level may ensure that the customer receives a working product. This would be likely to lead to the lowest warranty costs however there would be an increase in waste generated by processing unsuitable cores and parts.

The number of items being rejected at each stage combined with the costs of inspection and warranty could be used to analyse this problem using an equation based on the work of Deming (2000).

This presents an opportunity for further research in this area. Inspection cost optimisation models could be produced which would be able to give the most efficient level of inspection for a given product.

## **9.4 Research Methods Discussion**

In Chapter 2 a discussion was made of the relative merits of case study research. It was concluded that it was the most appropriate method since it is able to formalise knowledge that is held by industry and enables unexpected results to appear. These two major strengths of case study were vital to the success of this project. Firstly, according to Steinhilper (1998) the remanufacturing industry has been operating for over 50 years. During this time practitioners have developed a huge amount on knowledge which enables them to run their processes. In the case of inspection, this appears never to have been formalised in the way that has been done in this project. Benbasat, Goldstein et al. (1987) state that case research is the perfect tool for research in immature areas such as the one which has been studied for this project.

The second major strength of the research method in the case of this project was its ability to enable unexpected results to appear. A key part of this research was identifying the gap in theory whilst ensuring the theory developed would be useful to practitioners. The starting point of the research, looking at methods for meeting EU producer responsibility law requirements, is quite far from its ultimate contribution to theory. Using a less flexible method such as survey research during these early stages of the research would have meant that the interest in inspection showed by the companies involved during the initial case visits would not have become clear.

In Chapter 2 a description was given about how rigour was ensured during the research. This discussion was based around the framework for case research provided by Voss, Tsikriktsis et al. (2002). In general the research was undertaken as planned and the

decisions that were made about the method were found to be justified. In particular the decision to not tape record interviews was one that was justified. Without the presence of a tape recorder, interviewees felt free to discuss their opinions candidly knowing that they would be able to censure the notes in due course. In several of the interviews discussions were held about the interviewees' personal opinions about environmental issues. It is thought that the presence of a tape recorder would have prevented these opinions from coming to the fore. Although these items were not included in the case reports they aided in understanding the motivation of the interviewee.

In total meetings were held with sixteen companies. This is probably not a sufficiently large sample to be confident that all methods of inspection have been observed however Forza (2002) states that this may also be sufficient for large effects to be proven. All industries were covered and trade association representatives were included in some of the meetings. All of the companies that were used to create the framework were based in the UK. It is unknown if this had the potential to bias the results.

The research has been presented at several international conferences which are attended by practitioners from outside the UK. (Copies of the papers presented can be made available on request.) During these seminars there was no disagreement from the practitioners present as to the accuracy of the framework and generic models. Despite this, the framework should be used with caution in all settings to enable any differences to become clear.

In Chapter 7 the validation plan for the proposed framework was discussed. It concluded that a survey was the most appropriate tool to carry out the validation stage of the research.

Originally this was due to happen following a presentation by the author at a practitioners conference held by the Centre for Remanufacturing and Reuse. For this reason, to encourage a large response rate, the survey was kept extremely short and some constructs were only covered by one question.

Due to the postponement of the meeting an alternative plan was undertaken. This entailed taking the survey to practitioners, explaining the framework and models to them in person and finally asking them to fill the questionnaire. It was thought that collecting case study data alongside the questionnaire responses would lead to clear results. Unfortunately this did not work as well as planned. Having only one question to address some constructs meant that it was impossible to detect if the result had appeared from misunderstanding or misreading of the question. The notes from the meetings appear to show a more positive response to the research than that shown in the survey results. It is felt that if more questions had been asked in the survey and more time had been allocated for filling it then the results may have shown an even more positive picture of the research. Despite these shortcomings the survey showed that the research was relevant to the practitioners that completed the validation questionnaire.

Overall it is felt that the research methods used for this research were appropriate and well carried out. In order to further validate the research a new questionnaire could be developed which could reach a larger number of companies and cover a larger geographical area than just the UK.



## **9.5 Key Contributions to Theory**

This research has provided key contributions to existing theory. It has found that companies engaged in remanufacturing appear to run their processes using different strategies. These have been identified through an analysis of inspection procedures within companies which carry out remanufacturing processes.

This theory has led to the development of a framework for remanufacturing strategy which, coupled with IDEF0 process diagrams for each strategy, enables the user to observe the most appropriate inspection procedures for a given product. The research has also produced a generic process model which shows all of the distinct inspection and testing processes which are carried out during remanufacturing. This research has shown the purpose of each type of inspection at each stage of the remanufacturing process.

These contributions can be used by practitioners to develop new or improve existing remanufacturing processes. Researchers can use these contributions as a starting point for looking deeper into inspection processes and remanufacturing strategy.

## **9.6 Summary**

This chapter has presented a discussion of the differences between the strategies in the framework presented in Chapter 6 and validated in Chapter 8. It shows an updated version of the framework showing how all of the cases that were studied in the course of this research fit. An explanation has been made of the ClothesCo case which is significantly different to what would be expected in other cases. It is thought that this may be due to the fact that, on closer inspection, they do not carry out true remanufacturing since the end of life products they use are used to manufacture completely different items.

The research methods that were undertaken for this research were appropriate and adequately carried out. An attempt could be made in order to increase the generalisability and usefulness of the framework and models. This could be done by extending the survey questionnaire to include more questions for each construct and sending it to more companies over a wider geographic area.

## **CHAPTER 10: CONCLUSIONS AND FURTHER WORK**

This chapter concludes the research discussed in this thesis. It draws conclusions about the effectiveness of the research method along the how well it met the aims of this research itself. It will finish with some possible research questions which would take this work further.

### **10.1 Contributions to Theory**

This research has shown that there is a clear gap in theory within the area of remanufacturing strategy. It has shown that, although inspection has been identified as a key part of the remanufacturing process, no one has attempted to demonstrate exactly how these processes are currently carried out and if there are strategic differences in the way different companies carry out such operations.

This research has provided and validated a generic process for inspection procedures. It identifies the three specific stages of inspection that are carried out during remanufacturing processes and breaks them down into specific tasks and objectives. An understanding of how the process works, complete with its aims and objectives, is not only vital for practitioners by can also be used by researchers as a roadmap for further investigation into the area.

The main contribution of this research is its creation of a theory for remanufacturing strategy. It has shown that different remanufacturing companies operate their processes according to different strategies based on the characteristics of the product or products they are remanufacturing. It has identified that two key characteristics affecting strategy choice

are the value of the core and its reason for return. This research has provided and validated a framework showing how these characteristics lead to four distinct remanufacturing strategies that can be followed. This research has provided business process diagrams, drawn using the IDEF0 standard, to how the different strategies can be operationalised.

## **10.2 Research Limitations**

The research has used case studies and as such is open to many of the criticisms surrounding generalisability and extrapolation of results highlighted by Flyvbjerg (2006) and discussed in section 4.3. The aim of this research was not to produce something which is representative of the global remanufacturing industry but to present a theory that could be further tested and strengthened through the addition of further case studies and perhaps surveys in the future.

Due to financial and time constraints it has only studied companies with operations based in the UK. For the same reasons multiple visits were only carried out to two out of the three initial case studies. This means that the resulting theory is most likely to hold true for UK based companies.

A number of the interviewees requested that interviews were kept to within an hour. In some cases this was sufficient however in other more complicated process this led to a hurrying up of proceedings towards the end of the meetings. This was especially the case during validation case studies. Since the questionnaire was the last thing to be discussed in these meetings it is possible that this had an adverse impact on the results obtained.

The case visits were relatively short and so the amount of detail collected from each one was quite limited. Having said this, in general they were sufficiently long to capture sufficient detail about the processes to produce the theory presented in this thesis. Having short, single visit case studies allowed the researcher to visit more companies and to develop a clearer overall picture of the UK remanufacturing industry in a variety of different sectors.

More questions in the validation questionnaire could possibly have led to a clearer and more positive response to the research. Initially the questionnaire was designed to be used at a seminar about inspection in remanufacturing. The questionnaire should have been redesigned following the change in plan to present it directly to individuals on their premises. Factors that were addressed with only a single question could have been addressed by a series of questions to give a more detailed picture of the respondent's views.

Overall, despite these limitations, this research has produced a theory for remanufacturing strategy which can be strengthened and extended by the author and others in the academic community to give a theory which is relevant to remanufacturers globally.

### **10.3 Further Work**

There is very little literature available in the area of inspection during remanufacturing processes and different remanufacturing strategies. The outputs from this research will act as a framework for further research into inspection procedures and strategies. What has been made clear by this research is that each specific stage of inspection has its own specific aim and output each of which is used to gain confidence that the remanufactured product will function as required.

Further work should be carried out to decide the optimum method for carrying out these specific inspection tasks. It should investigate the role of automated testing rigs, laser measuring and manual measurement. It should attempt to quantify how much more accurate these are than 'scratch and sniff' techniques so common in the automotive industry.

Some of the cases that were investigated for this research appeared to follow a 'horses for courses' approach to remanufacture. The most appropriate strategy was selected for a specific item based on information that was known about the product. Key knowledge such as knowing that an item has never been in service and is a commercial return has the ability to change the remanufacturing strategy and remove the need for unnecessary disassembly. For example an item that has simply be removed from its box by a customer before being returned can be treated with different strategy than one that has had 5 years of heavy use. The unboxed item may simply need a Strategy III test, repair and re-box operation whereas the worn item may require a Strategy I complete disassembly and rebuild. Processing items without the need for disassembly has the potential not only to reduce cost but also to result in a more reliable product.

An investigation should be made into the cost implications of this mass customisation style approach and the mass production 'bang-bang', processing all cores using the same production line, common in the automotive industry.

Emerging technologies such as additive layer manufacturing have the possibilities to manufacture or repair parts for products which are being remanufactured. This has the

potential to greatly reduce the cost of parts to the remanufacturer and enhance their flexibility. Research should be carried out to see how all of these technologies will change the way remanufacturers operate in the future.

It has become apparent that a substantial amount of testing and inspection is carried out in remanufacturing processes. It is this which creates knowledge about the product so that it can be confidently declared as good as new. An analysis should be carried out in order to understand if all of this inspection is absolutely necessary. There is a trade off between the costs of inspection and the additional costs of rework and/or product returns caused by removing some levels of inspection.

Knowledge enables the correct strategic decision to be made for remanufacturing on a product by product basis. In some of the cases studied this information was collected from the last user, from the product itself and in others from a product maintenance log. One opportunity is new technologies such as 'green ports' where data relating to a specific product is embedded on a chip within the product itself. These technologies have the potential to increase the efficiency of remanufacturing inspection processes. The information provided by these technologies should be carefully matched with the specific inspection outputs developed in this research. This may enable many of the inspection processes to be replaced by information collection and analysis. Researchers should use the processes that have been documented in this work to state exactly which of the stages of inspection the technology they develop could replace. Perhaps it will only be the core level inspection process or perhaps it can be used to identify the appropriate remanufacturing strategy for the product or specific item in question.

During the case studies it was often stated that spare parts were the largest cost for remanufacturing companies. Effective use of spare parts is key to the profitability of remanufacturing in some sections. The development of specific processes to analyse the remaining life of parts will enable more parts to be used with confidence and hence reduce the costs of new parts.

Whilst carrying out case study interviews patterns started to emerge within different industries. There were similarities between the ways in which OEMs changed their opinions of the remanufacturing industry over time. In less mature industries OEMs are hostile to remanufacturers and redesign their products to try and stop remanufacturing activities. This situation was observed in the more mature industries when they first started remanufacturing. More recently OEMs have seen the benefits from remanufacturing and have even formed partnerships with remanufacturers supplying them with parts and working together to establish standards for remanufacture. This area could be looked at in more detail. Perhaps it is the case that all industries go through this sort of cycle or perhaps there was something specific to the industries in which these partnerships were formed that has made them so successful.

This work has effectively provided a research route map which can be used for further investigation into the area of inspection in remanufacturing processes. Having established the nature and purpose of each of the inspection stages currently used in remanufacturing new investigations can be made into the appropriate removal or replacement of these stages with technology or other methods that have been discussed.



Remanufacturing is a method of creating low cost, socially responsible and environmentally less burdensome products. Development of the remanufacturing industry is becoming a key strategy for reducing waste, environmental degradation and increasing the number of skilled jobs in the European Economy. The framework that has been produced in this research, along with the inspection process diagrams can act as a starting point for the design of new remanufacturing processes.

This research has provided vital tools which can be used to improve the efficiency of remanufacturing processes as well as providing a route map for further investigation into this new and interesting area.

## 10.4 Future Research Questions

There are many specific research questions that follow from this research. These are as follows:

- Is it practical to remove inspection stages within the remanufacturing process and can this be done whilst maintaining final product reliability and quality?
- How will emerging technologies such as green ports change the way remanufacturing inspection is carried out? How will the specific aims and objectives of the different stages of remanufacturing inspection be met using these technologies? Are there more cost effective ways of accomplishing these aims other than the ones identified in this work?
- Is there a common remanufacturing industry cooperation cycle where OEMs start by blocking remanufacturing but in time start to work together with the industry?
- Does the ability of additive layer technology to repair and make replacement parts reduce the need for OEM cooperation within remanufacturing?
- How effective are the framework and inspection process diagrams developed in this research at helping companies in establishing new processes? Are they sufficiently robust to be used alone or do companies also required assistance from an industry expert?

# **BUSINESS PROCESSES AND STRATEGIC FRAMEWORK FOR INSPECTION IN REMANUFACTURING**

## **APPENDICES**

Mark Errington  
May 2009

## Appendix A. Invitation Letters to Initial Case Studies

Room 204  
Harrison Building  
Exeter University  
North Park Road  
Exeter EX4 4QF  
m.errington@exeter.ac.uk  
01392 263613  
27<sup>th</sup> April 2006

Operations Director  
CompCo

Dear,

My name is Mark Errington and I am a first year PhD student within the Engineering Department at Exeter University.

I know of CompCo through one of the projects you supplied computers to in Gulu Northern Uganda. I have seen first hand the impact your computers have on community based projects in East Africa and I think that giving computers a second life is a key component in reducing computer waste sent directly to landfill.

My PhD is based in Operations Management for Sustainability and will look at how new EU product 'take back' laws will provide additional opportunities for extending product lives and therefore reducing global consumption.

The PhD aims to develop a tool which could be used in order to make the decision for the best treatment option for end of life products. Of these options the PhD is most interested in Repair, Refurbishing, Remanufacturing and Recovery of parts. If it is possible I would like to carry out a case study based research around your refurbishing of computers at your warehouse. There is more information about the PhD and my area of interest in the enclosed document.

If you think you would be able to help me with this request then perhaps we could meet at your office to discuss the project in more detail? I think it is essential that the not for profit sector is not ignored when research of this nature is carried out and I believe it will be mutually beneficial to both parties concerned.

Yours Sincerely

Mark Errington  
PhD Student – Operations Management for Sustainability

Sent via Email to MilCo

My name is Mark Errington and I am a first year PhD student within the Engineering Department at Exeter University.

I spoke to XXXXXX who is known to me through his work with Exeter University last year. He is positive that you might be interested in participating in this project with us.

My PhD is based in Operations Management for Sustainability and will look at how new EU product 'take back' laws could provide additional revenue streams for the manufacturers affected by them.

The PhD aims to develop a tool which could be used by industry in order to make the decision for the best treatment option for end of life products. Of these options the PhD is most interested in Repair, Refurbishing, Remanufacturing and Recovery of parts. If it is possible I would like to carry out a case study based research around two of your processes at your manufacturing facility. There is more information about the PhD and my area of interest in the attached file.

I do hope that you will consider this request for a case study within your company. I believe it will be mutually beneficial to both parties concerned.

Yours Sincerely

Mark Errington  
PhD Student – Operations Management for Sustainability  
Room 204  
Harrison Building  
Exeter University  
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01392 263613  
m.errington@exeter.ac.uk  
14<sup>th</sup> November 2006

Dear ,

My name is Mark Errington and I am a second year PhD student within the Engineering Department at Exeter University.

My PhD is based in Operations Management for Sustainability and will look at how new EU product 'take back' laws will provide additional opportunities for extending product lives and therefore reducing global consumption.

The PhD aims to develop a tool which could be used in order to make the decision for the best treatment option for end of life products. Of the 'return to use' options the PhD is most interested in direct Reuse, Repair, Refurbishing, Remanufacturing and Recovery of parts. If it is possible I would like to carry out a case study based research around your activities. There is more information about the PhD and my area of interest in the attached file.

If you think you would be able to help me with this request then perhaps we could meet at your facilities to discuss the project in more detail. This research will produce a tool that will be beneficial to both parties after the research project has been completed.

Yours Sincerely

Mark Errington  
PhD Student – Operations Management for Sustainability

# **A Conceptual Framework of Take-Back Options**

**Mark Errington, PhD Student, Exeter University, UK**

## **General Objectives**

Legislation increasingly requires companies to take back their end-of-life products. The aim of the PhD is to establish a conceptual framework for the management processes required for the take back and treatment of taken back products and to create a toolkit for analysing the reusability of an individual product.

The PhD will focus largely on the choice of the correct reuse option both in terms of environmental and economic performance. Rather than outsourcing this huge part of the business, the PhD aims to seek out ways in which it can be integrated into the traditional forward business and create additional revenue. Japan introduced similar laws in 1995 and is leading the way with companies such as Sony's recycling division reporting sizable profits.

## **Project Context**

Consumers are demanding more environmentally friendly products and in many cases environmental performance is becoming an order winning criteria. Perhaps as a response to this or perhaps for the same reasons there is an increasing amount of research being carried out in the area of environmentally friendly manufacturing and so called 'closed-loop' supply chains. The general structure of these loops is that product passes from the manufacturer to the customer; once it is no longer of any use for the customer it is returned to the manufacturer who returns it to the market in one of many ways. The manufacturer can recycle products on a complete item, component or material basis - the so called reuse, remanufacture, recycle decision. The products produced through the remanufacture and recycling options are of similar quality to the original parts and so continue to travel around the loop. Some products are not suitable for resale into the original market but still have value and are sold in secondary markets. A key aspect of this research is to look into how the reuse, repair, recycle decisions are made and if improvements can be made to improve the efficiency of these decisions.

It is though that accurately estimating the cost of returning a product to use is a key element in ensuring the profitability of reverse supply chains, where a post consumer product is used as a feedstock into a process.

Companies are starting to realise that a good environmental image will help them to compete effectively in today's market. Consumers are starting to look for the lowest environmental impact as one of their deciding factors when making product choices. In Japan there is even some legislation requiring government departments to select the least environmentally damaging product of the range for their offices. It is, perhaps, not too difficult to imagine legislation of this nature in Europe in the near future.

This is not the only reason that manufacturers need to become more 'green'. Recently the EUs new producer responsibility laws came into force. Amongst other things these require the take back and treatment or disposal of many commonly purchased electrical items such as fridges, computers and mobile phones. There is also separate legislation that requires the 'take back' of End of Life Vehicles. Companies such as Boeing and Airbus believe that similar legislation relating to aircraft end of life treatment will be produced in the near future. The producers of products covered by the current legislation are not only responsible for the collection

of the products but they must also ensure that they are disposed of according to strict guidelines within the legislation. They are also financially responsible for all of these operations.

One of the most economical ways of recovering value from the used products is to remanufacture old used product into products that meet or exceed the customers current needs or expectations. This has the least impact on the environment as much of the energy invested into bringing the product to its current state, during manufacture, is retained. The products created can often be sold in the original market or secondary markets and in some cases have been shown to generate more profit than sales of new products.

Unfortunately not all items returned are suitable for remanufacturing. A key method for making the process streamlined and profitable is to identify items that would be better suited to a different reuse option. Items that are too costly to remanufacture should be identified and sent for recycling early in order to reduce storage and processing costs of useless parts. One of the aims of the PhD is to identify the best technique for doing this. Some say that collecting information from the products' user is the best approach whereas others, such as the Bosch hand tools division, are collecting key data through the use of a 'green port' contained within the equipment. Neither of them mention which of these techniques is likely to be the most cost effective and provide the most useful information.

This is not likely to be the only new business process that will be required by industry for it to operate within a closed loop. The rate and quality of returns is likely to cause complications for the manufacturing systems. Remanufacturing is a push based system, predicting inflows of products and their quality is likely to play a key role in capacity planning, materials requirement planning and stock control.

The aim of this PhD is to identify new ideas and concepts that will assist the remanufacturing operations of companies and turn the closed loop supply chain into a profitable reality for more businesses within the manufacturing industry.

Literature sometimes gives the impression that the industry is in its infancy. This is not the case. Firms have been remanufacturing parts for the automotive and aerospace industries since the birth of the industries themselves. There is a great deal of experience and knowledge in these sectors about the business processes involved in running a successful remanufacturing process, although it is not widely understood or codified. The research will take a case study based approach to establish the differences in processes required for different product types. It is thought that a remanufacturing firm operating on a low cost, low risk item such as disposable cameras or inkjet cartridges is likely to involve different processes than the remanufacturing of landing gears for passenger aircraft. But it is likely that there are common processes that could be identified and developed for use by other industries.

Researchers such as Guide have looked at the macro situation of industry as a whole including strategic product decisions such as design for X. Little work has been done to date on the alternatives and the pressures at the level of the business, and there is as yet no firm theoretical base for the strategic decisions that will need to be made – in fact the decisions themselves have yet to be identified. Through initial work in case study companies this research aims to identify and solve some of the problems that must be faced.

Becoming responsible for the disposal of end of life products will require a great deal of change in industry. Those who do not change will have costly disposal operations to fund. Those who seize it as the great opportunity that it is will create a new profit centre within their business. This research will assist industry in making the right decisions during the operation of their businesses within the developing era of green manufacturing.



## **Appendix B. Initial Case Visits Notes**

### **CompCo**

CompCo refurbishes between 1,400 and 1,700 computers per month. The vast majority of these are desktop computers however they also refurbish laptop computers. The standard refurbishing lead time is two weeks and stock does not spend much time in the warehouse. CompCo works on a not for profit basis and provides computers to educational establishments and charities in various locations throughout the developing world. The refurbished computers are all sold for a fixed price per unit and there is no definition between different computer specifications. The computers refurbished are Pentium 3 & 4 or equivalent.

A large number of computers donated for refurbishing are donated in large batches. A charge is made by CompCo for the collection of these items. These donations depend on the replacement of old computer systems with new ones. Therefore they are closely linked with the strength of the economy. During times when demand and capacity outstrips supply companies are called by the marketing department in order to encourage them to donate their old machines. There are also times when computers are purchased in order to meet demand. It was unclear if these were refurbished or not. These computers are mainly purchased from other not for profit computer refurbishing companies but from time to time they are also purchased from commercial operations.

Computers are sorted at source as much as possible. Only high specification, working machines are accepted. Computers that are found to not work or to be the wrong specification are recycled with the cost, plus a premium charge, borne by the donor. This is done in order to stop people using the company as a means for disposing of waste.

CompCo believes that the computers it supplies should have a working life of 3 to 5 years. Their computers have been found to perform well and meet this requirement. The computers also appear to outperform new equipment, they think that this is due to the good quality brands of machines that they deal with and the proven reliability of the machines after years of use.

CompCo refurbishes working equipment and so is not dealing with waste. For this reason it is not licensed under the waste act and so can freely export computers to wherever they are needed. Despite this it was thought that the WEEE directive would lead to a large increase in donations to CompCo, mostly from companies wanting to reduce the amount of WEEE they produced. These have not yet materialised. It is thought that this is due to the fact that the legislation has still not come into force in the UK. It is a possibility that computer manufacturers will contact companies like CompCo to reduce their WEEE burden. In the mean time, while business WEEE is the responsibility of businesses, there should be a large increase in the number of computers donated.

A major source of concern with the refurbishing of computers is their fate once they come to the end of their second lives. To combat this a computer refurbishing firm known to CompCo has started to operate in the following way.

The company takes donations of computers and refurbishes them in a similar way to CompCo. The majority of these second life computers are then sold to customers overseas. A recycling bounty is created at the time of sale which is used to cover the transport and recycling of computers in the UK at their end of life. CompCo is sceptical that they will be able to locate their computers at their end of life in order to return them to the UK and send them for recycling.

## **The refurbishing process**

Computers arrive at the CompCo's facilities in an unknown state. Information on the condition of the computers is sometimes given by the donor but it usually turns out to be inaccurate. For this reason all of the decision making about the suitability of a machine for refurbishing is made on the basis of a visual inspection, the model of the computer and an estimation of its age. If it is decided that a computer is not suitable for remanufacturing it is sent for materials recycling. Occasionally these computers can be cannibalised if there is a need for the parts. There is currently someone known to CompCo who is developing a data base of parts that are contained within different computer models.

During the next stage of the process, data is erased and the machine specifications are found using diagnostic software. Based on the details obtained a decision is made if the computer is suitable for reuse; or alternatively if it requires upgrading or cannot be used at all. The discarded computers are then be cannibalised for parts.

Computers and peripherals are kept together while they pass through the process. This is so that colour matches can be maintained and working computers are kept together as much as possible. There is no tracking system used to trace the progress of desktop computers through the process. It is thought that use of such a system would cause a large amount of additional work but would have few tangible benefits. Having said that there is a system in place for laptops. There is no overall stock control system for parts or computers for the same reason. The warehouse is reasonably small so manual stock checking is a simple activity.

There are no standard part replacements made but computers are cleaned and brought back to a working condition before they are shipped. Experience has found that the most likely part to fail during second life use is the PSU. This is due to the fluctuating power supply in many of the locations where the computers spend their second life.

## **JetCo**

JetCo is a manufacturer of Gas Turbine generator sets and complex components based in England.

The generator sets utilise the Rolls Royce – Allison 501 engine. This is the same engine that is used to power the Hercules aircraft.

The generator sets they package give cogeneration of electricity and heat and are 80-85% efficiency. In some models the heat is used to raise steam which can be injected back into the engine to enhance its power. Their current range generates between 2.5 and 6 MW of power and only require overhaul after over 30,000 service hours. This is in contrast to diesel generators which often only run for a total of 16,000 before major overhaul work.

JetCo have sold 230 501 engine based generator sets in the past 20 years and hold maintenance contracts for the vast majority. Maintenance contracts are sold with most units and last for 5 or more years. It is thought that more money is made through after sales services, such as through service contracts, than in the sale of new units. The contracts stipulate a guaranteed system availability, typically 95 to 98%. The units are linked to the JetCo head office via a SCADA system. The reason for failure of a system is often known before service engineers even arrive on the site where the system is located.

## **Engine Repair / Overhaul**

Every 2,000 running hours a crew carry out a visual inspection of the generator set on site. The engines can be removed and stripped down into 3 main sections at site and inspected to highlight any faults. If repairs are deemed necessary then a decision is made to determine if the job can be completed on site. If this is feasible then an estimate is made about how long the job will take. If the repair cannot be carried out on site or if it will lead to a breach of the guaranteed availability stipulated in the contract then it will be removed from the system and replaced with a rental engine. The engine is then transported to JetCo's facilities for repair.

The engine are the most common component within the genset that will require work, this is due to the extreme conditions it experiences. However every part of the genset has a lifetime and although not commonplace the AC generators have required work/overhaul.

The engines are sent to the JetCo facilities for processing. Once processed the engines are returned to the same customers they came from and are swapped back with the rental engines.

During an overhaul, the engines are disassembled and worn components are replaced with new. Parts that are known to wear and are submitted to the most extreme conditions are given the most detailed inspection first. Once the engine is reassembled it is put through the same test procedure as a new engine, and then swapped back with the rental engine at its location.

## **Other Repair Inspection Procedures Carried out at JetCo**

Much of the equipment that is used on site for the manufacture of complex components are one of a kind and cannot be purchased elsewhere. Many are the only machines in existence that can perform the tasks required, and some of them are very old indeed. They are maintained in house and replacement components often have to be fabricated in house.

The protective cases that are used to transport the engines are constructed from steel and are reused. At some point the cases become unusable and new ones must be acquired, it was not clear how this decision is currently made.

Gen sets that are sent to France are only used for 12 years this is due to the French cogen tariff. After this they are often bought back by JetCo, and replaced with a new package, the used unit is then refurbished and resold. They are often sold to markets in North Africa. This also applies to generator sets that are returned after a customer no longer has a need for them, due to insolvency or another reason.

### **Other Relevant Activities**

It is the vendors who decides if an engine can be reused after initial use or if it must be taken out of service. These engines, in addition to engines declared to be Beyond Economical Repair by other companies are purchased by JetCo. These engines are disassembled, and any reusable parts are recovered. These are used for repairing rental engines but never for replacing parts in customers' engines.

In theory only the engine, gearbox and alternator need to be replaced for a French gen set to be declared 'new' however it is considered to be more expensive to do this than to supply new equipment.

A continuous process is carried out to determine the profitability of each maintenance contract over its life.

## **MilCo**

MilCo is a manufacturer of many defence and energy related products. They have an annual turnover of £11M. Approximately 90% of their business is based in the defence industry with the remainder being made up of products for the energy sector. This currently comprises gas and oil industry related products but they also plan to increase their product range in the renewable energy sector.

In the defence industry their main customer is the Ministry of Defence. They design, produce and support the following products to the industry;

- Sonars, signal and data processing equipment
- Data communications equipment
- Mechanical control equipment

A typical product of MilCo's has a life cycle from conception to disposal of 30 years. This often includes some aspects of repair and remanufacture of the equipment. This occurs both where the equipment is in use and also at their production facilities.

MilCo has been involved in the remanufacture of its own and its competitors products since it started doing business. They are probably exempt from the WEEE directive as they are part of the defence industry. Despite this they find their remanufacturing and repair operations very profitable.

The highest volume products that are currently remanufactured at their facility are Product A and Product B. The remanufacture of both types of product is closely aligned with their forward manufacturing operations using both the same facilities and production staff.

In the future MilCo expects to re engineer old products as well as its current operations in order to enhance their performance and reliability.

## **Product A**

MilCo offer 'Contractor Logistics Support' ie they guarantee the ongoing availability of the item for use. This requires stocks to be held to instantly replace failed units. Stocks of parts are also held for repair. Failed units are returned by the MOD when they are no longer functional. MilCo is paid for their disposal. Where possible, working parts are recovered, collected and used in the production of towed arrays when sufficient parts have been collected.

The company has a contract which requires it to replace non functional products with ones that function correctly within a certain time period. It is also a condition of their contract that they must supply equipment that is working for a specified amount of time per year. They are also responsible for servicing the equipment at their customers' sites. The service contract arrangement is seen to be a win-win situation by both customer and manufacturer. One increases its overall profit from the product and the other decreases its procurement costs. It is the opinion of the Managing Director of the company that this is due to a 'reduction of bureaucracy on the part of the customer'.

In this particular case the company has an additional advantage when it come to stock holding. There are 4 different types of sonar but they are modular in design. It is therefore possible for MilCo to assemble to order whereas the MOD historically had to maintain stocks of each item.

One aspect of the contract that differs from standard service contracts is that the company cannot dictate when the items are returned to them.

The company is required to provide a service rather than a product. From the point of view of the customer it does not matter whether the equipment that is used to provide the service is new or remanufactured. If the equipment that is supplied requires additional repair due to its age or the number of times it has been reused then it would be the company that provides the service that would be required to fix it. The remanufactured products are considerably less expensive to produce than the products made from new parts. The service contract is at a price fixed for a set period (5years). Providing the service only with new equipment would be unlikely to be profitable. Utilizing a proportion of remanufactured or second life equipment as part of the contract will increase the profits of the company.

Both new and remanufactured products are assembled using the same production facilities. Production of remanufactured products is more complicated when it comes to testing and calibration. Despite this added complexity, the production time for a new product is 6 weeks and that for a remanufactured product is 4 or 5 weeks.

Once received the returned items are visually inspected, tested to identify faulty components and finally assessed for component age. If it is likely that the components are likely to become obsolete during the next life cycle then they are replaced.

There are some production problems when remanufacturing the used assemblies. The products are filled with kerosene. This leaches the plasticisers from the wire insulation within the assembly which makes them brittle if they dry out. There is clearly a need for alternative materials of construction for these items.

Repairs are carried out on the items based on the findings of tests.

## **Product B**

MilCo have a fixed place contract to remanufacture these items. They are returned to MilCo on an irregular basis. They are used as part of installations totalling 768 units and are delivered to the factory for remanufacturing in array groups of 768 or 384 units. The casing of the items is made from a specialist alloy and is very valuable. This is recovered along with the tail and glands. The active element in the product is also valuable however it is often difficult to remove due to being glued in place during its first manufacture. Although difficult it is sometimes possible to remove the element. This is done whenever possible. To make the items easier to remanufacture in the future they are currently fixed into place using soft glue that can be removed during disassembly. Other parts of the product are not currently recoverable.

Minor variations in the products and the need for accurate frequency matching at a range of operating frequencies require stocks of active elements and other components of many different settings to be maintained. These stocks are owned by the company but have zero book value. It is thought that the storage and finding costs of the unit are small when compared with the savings made on finding a match.

In future more functionality and reliability will be expected which will come from modifying existing units and service arrangements.

## **Appendix C. Invitation to Research Sent Via the Centre for Remanufacturing and Reuse**

Dear Sir/Madam,

My name is Mark Errington and I am a second year PhD student within the Engineering Department at Exeter University.

The research is based in the emerging field of Operations Management for Sustainability and will look at how new EU product 'take back' laws will provide additional opportunities for extending product lives and therefore reducing global consumption.

Remanufacturing is seen as a key solution both to reducing waste and for compliance with the new EU laws.

The research is concerned with how the assessment is made to establish the suitability of a given core or components of a core for processing. Processing cores that are uneconomical to remanufacture and discarding cores that are profitable to remanufacture both lead to financial losses.

This research will use case studies to find out how this decision is currently carried out in the remanufacturing industry. It will use there to develop a framework of the factors involved and will provide insights to improve the cost efficiency of this decision making process.

For more information about the research project please see the document attached.

If you think you would be interested in becoming involved with this research by becoming a case study then perhaps we could meet at your office to discuss the research in more detail?

As a case study company you would have to agree to meet for a maximum of 4 one hour sessions at your facilities over the next six months in order to discuss your process. The details of your process will be held in the strictest confidence and all company names will be disguised in any research that is published. Any publications will also be submitted to you for your approval before they are published.

Your involvement in this project will ensure that the research that is carried out it is relevant and useful to the industry. The research aims to solve problems that are faced in the industry and will provide insights to improve the profitability of your remanufacturing processes.

I do hope that you feel you would be interested in becoming involved in this interesting area of research.

Yours Sincerely

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**19 April 2007**

**Towards a Formal Process of Beyond Economical Repair Decision Making**  
**PhD Research Brief**

Recent European legislation requires the producers of certain equipment to be responsible for its disposal at end of life. They are not only responsible for retrieving the used products from their end users but are also responsible for recycling them and at the same time meeting minimum recycling rates. Material recycling is clearly preferable to land filling, however most of the value added during manufacture is lost.

Many consumer products are still working at their end of life. There is an increasing number of companies that collect these products and return them to market both in the UK and abroad. These products provide a lower cost alternative to buying new products. The companies that return these products to market appear to have been very successful both as not for profit and traditional organisations.

Other products reach their end of life because of an accumulation of rectifiable faults, the wearing of a small number of components within a product or sometimes because of their age or amount of use. There has been a long tradition of remanufacturing in the automotive parts industry and recently manufacturers in other industries such as Hewlett Packard and Xerox have started to run very large remanufacturing operations.

Preliminary case studies have been carried out in order to find out some of the difficulties faced in running such operations. It was found that the case study companies share one very difficult task in common. This is how to determine if a returned product is suitable for remanufacturing and subsequent resale. This is commonly carried out through inspection, testing and an estimate of the work required being produced. In the defence industry this task is referred to as the 'beyond economical repair' (BER) assessment.

It is thought that this task is particularly important in the running of an efficient remanufacturing process. Accurate predictions need to be made about the amount of work required for an item and the cost of these repairs. In addition to this, an accurate prediction about the value of a product once it is resold must be made. Processing products where the cost of repair outweighs that of the sale price is clearly a waste. Disposing of a suitable item is not only a lost opportunity but the money invested in transporting the item to the processing facilities and inspection costs are also lost.

This research will use case studies to develop an overall picture of how these decisions are currently made in the remanufacturing industry. It will develop tools and frameworks from these cases in order to standardise and improve the efficiency of the processes involved.

Remanufacturing is an area which is likely to experience a large amount of growth as environmental concerns and energy costs continue to increase. Developing cost efficient processes at this stage will help remanufacturing organisations to continue to be competitive long into the future.



## **Appendix D. Case Study Discussion Points**

- 1) Can you please describe the process of remanufacturing in your organisation.
- 2) How important are these operations with regard to your overall manufacturing operations?
- 3) Does dealing with returned products complicate your forward manufacturing processes?
- 4) Are you the OEM of the products you deal with?
- 5) Does this make processing more easy/difficult?
- 6) How diverse is the range of products you deal with? (1 model, 1 manufacturer, 1 category of equipment)
- 7) Are the products that are returned to you functional or fashion based?
- 8) Where are your remanufacturing operations located?
- 9) What is your customer base?
- 10) Do you regard your customers to be those sending used products to you or those who buy the products you remanufacture?
- 11) How do end of use products return to you from the consumer?
- 12) Are these products mainly functional or non functional?
- 13) How do you determine if an item is suitable for processing?
- 14) What do you do with items that are not suitable for processing?
- 15) Who is financially responsible for this?
- 16) How do you think the implementation of the WEEE regulations will affect your business?
- 17) How do you plan to change your operations in order to comply with these regulations?
- 18) Is there more demand than supply for your processed equipment?
- 19) Does the person who purchases your equipment make a distinction between new and processed equipment.

## Appendix E. Inspection Case Study Notes

### CopyCo

CopyCo are a large multinational corporation manufacturing photocopying machines on a global scale. For decades they have leased machines on a cost per copy basis. This cost includes all consumable products such as toner as well as machine maintenance. Due to the large number of end of lease machines the company had to deal with it became an expert in remanufacturing.

Currently only fuser roll remanufacturing is carried out at the UK site. The roll applies heat and pressure to the toner and paper fusing them together. It consists of a turning mechanism, a metal roll which is coated in polymer and a bearing. Over a period of time, which varies greatly by machine, the coating wears out or becomes contaminated and it must be replaced. A module containing the fuser roller is removed from the copier by its user. It is sent to CopyCo at various locations where the fuser roller is removed and sent to either the UK site or one in the US for remanufacturing.

The rolls are sorted into categories. The number of categories varies depending on the model in question. For some products there will only be use and reject for others there will be two categories which may be reused. It is thought that the skill level required to carry out this sorting is similar to that required in new product inspection.

Approximately 70% of the rolls that are received by the company can be remanufactured. Others are rejected due to damage that was caused during use or shipment to the plant. It was suspected that this could be improved to as much as 90% if handling practices were good. Some rolls that pass this initial inspection may fail inspection at a later part in the process, the situation is the same as for new rolls.

Once the rolls arrive they are inspected for obvious physical damage. Those that are rejected are either sent directly for recycling or are disassembled to facilitate component recovery. Firstly rolls are disassembled. A triage principal is used at this stage; some of the parts are always reused, some are always recycled and others are inspected to determine their fate. For bearings, this decision is based on how much use they have had. Parts, other than the roll itself, that are deemed to be reusable are separated and made available to the final assembly area.

Rolls are sent to a jet wash machine using a water knife at 40,000 PSI, which strips used coatings from them. Each is then inspected using a laser system to ensure quality. After this stage, all rolls, both used and new follow the same process. (A comment was made that if it was required, there would have to be no distinction made between the new and used rolls.)

New rolls are manufactured in a metal work area within the building. Both the new and used rolls are sent to one of two following stages which apply the rubber coating to them.

The rolls are washed and cleaned, grit blasted to provide a rough surface for polymer adhesion. They are warmed and sprayed with a new coating before being sent to an oven for setting. Some of the rolls that are produced on this line require a heat proof coating to be applied to the inside. These rolls, which are mainly of aluminium construction, are then inspected in an additional stage to insure that this has been done adequately.

Rolls which are sent to the second coating line are processed as follows. The rolls are put through two stages of washing, they are again grit blasted to aid adhesion. They are coated with special rubber in a solvent before

being sent to an area where the solvent has an opportunity to vent. Finally they are sent to an oven where final setting takes place.

Some of the rolls that are produced by the processes have historically required grinding. The number of units that now require this operation is though to be less than 1%.

After this the rolls is assembled into a new unit using both new and previously used parts.

During the first three months of the production of a new product these are assembled into fuser modules in the plant. After this period, once all problems have been corrected, the processed is outsourced to China and the Czech Republic.

It is not known how many times a tube can be reused in this way but it is thought that it would be at least as long as the lifetime of the product in which it is used.

### **Problems Faced**

It was identified that the main problems faced by CopyCo in its remanufacture of fuser rolls were the cost of shipping and the long journey times of cores and products in container ships.

## **CoreCo**

CoreCo is a core broker that has been operating within the remanufacturing industry for the past 15 years. They deal in remanufacturable automotive components from cars and trucks. CoreCo source and supply cores all over Europe for both left hand and right hand drive vehicles. They have a smaller warehouse in continental Europe, which acts mainly as a transit warehouse, as well as their main facility in the UK. CoreCo have approximately 400 customers some of these customers buy a very small number of cores at a time others buy thousands. 60-70% of the cores supplied by CoreCo are sent to remanufacturers in mainland Europe.

CoreCo deals in; turbos, alternators, starter motors, AC units, diesel pumps/injectors, ECUs, ABS, mass airflow sensors, both manual and auto gearboxes, engines, prop shafts, drive shafts, brake callipers, tachographs and steering racks as well as many other parts.

Remanufactures have three routes from which they can obtain cores for remanufacturing.

- Exchange schemes, where a failed core is required in order to purchase a remanufactured item. (at best these schemes recover cores for 85% of the remanufactured products sold, some of which cannot be remanufactured.)
- OEM warrantee replacements.
- Core brokers such as CoreCo.

Cores are usually bought from the stocks held by CoreCo via a stock list sent out by the company. A customer may also send a search list to the company detailing cores which they would like to purchase. After a search list is received, cores will be sent from stock if they are available or a specific search may be undertaken in order to find them.

CoreCo sources cores mainly from the three following routes;

- Vehicle dismantlers
- Breakers yards
- Warrantee returns (from OEMs)

Cores are located by one of the ten buyers working across Europe. The buyers then inspect them to identify the part number of the cores and to identify damage which would make them impossible or unprofitable to remanufacture. At this stage cores are inspected without disassembly. They are inspected in order to identify obvious major damage, bracket damage, electronics burn out and restriction to movement. If the cores fail any of these inspections then they are not purchased. The cost of scrapping any cores found to be faulty after purchase is borne by CoreCo. The company works closely with breakers yards and vehicle dismantlers to find the cores for which there is currently demand for or there is likely to be demand for in the future. On occasions they also purchase excess stock from dealers.

Some disassembly is sometimes carried out on items entering the warehouse, disassembly of dressed engines for example; however this is not normally the case. After the cores arrive in the warehouse they are sorted by part number. This is a very skilled job as there may be up to 4 or 5 part numbers for one OEM number. Some components, such as steering racks, are not marked with their part numbers and so require even more skill to be sorted accurately. As they are identified, cores are inspected in order to assess their potential for profitable remanufacture.

The method of testing cores differs by part type. They are all assessed for major obvious damage. Parts with moving elements, such as turbos, are tested for float and movement, electrical items, such as starter motors are

also tested for burn out. Burnout is tested for using a smell test whereas other inspections are carried out visually. All of these inspections are carried out without disassembly of the cores.

Some cores held by CoreCo may be functional however this cannot be guaranteed so they are never sold on this basis. If a core is deemed to be unsuitable for remanufacture by a customer then they are only given credit for the core if it is due to a fault that should have been identified by CoreCo. If this is not the case then the core is scrapped and the cost is borne by its purchaser.

### **Major Problems Faced**

One major problem that was detailed by CoreCo was finding the right core at the right time. It was stated that for the first 3 years a part is in use it is not remanufactured and hence demand for core is low. After this period, demand increases almost exponentially.

Another problem faced by the industry was felt to be the decline of remanufacturing in the UK, most of which has moved to Eastern Europe. It is thought that this is due to the fact that 70% of the cost of remanufacturing is labour. The cost labour is significantly less in Eastern Europe compared to the UK.

Other challenges that are faced are more technical in nature. Parts that were traditionally electronic are becoming more mechanical and parts that were traditional mechanical are becoming more electronic. This means that remanufacturers will need to broaden their skills base in order to remain competitive. Many parts also now communicate with the car's ECU making them more difficult to replace by non OEM garages and amateur mechanics.

It is thought that China is becoming more interested in remanufacturing and may start to put even more competitive pressure on European remanufacturers in the near future.

## **ClutchCo**

ClutchCo is an independent family owned company which was founded in 1977. Initially they remanufactured commercial clutches only. As the company grew they also started to remanufacture car and light commercial clutches. This was due to the large volume of potential sales available. By 1985 most all of their products were sold directly to a single motor factor. However after this company ceased trading ClutchCo has expanded their customer base. Today they supply to over 100 different customers of different sizes from large factor accounts to national distributors.

During the early to mid 90s ClutchCo was operating two shifts and remanufacturing over 1,800 clutches per day. Due to changes in the market for remanufactured clutches this has dropped back to one shift consisting of 2-3 staff remanufacturing 70-80 units per day. It is believed that this is mainly due to two reasons;

- Clutch design and clutch friction material has improved increasing the life expectancy of a clutch from 30-40,000 miles to over 100,000
- New clutches can be imported from China at roughly half the cost of remanufactured clutches.

In order to survive the company diversified into the sale of new clutches and brake disks. Currently around 10% of the brake disks are from European manufacturers with the remainder being imported from China. 20% of the company's business is currently in the sale of new and remanufactured clutches with the remainder in brake disk sales. It was explained that the increase of efficiency of friction material prolongs the life of clutches but shortens the life of brake disks. Therefore as the market for clutches is declining then market for brake disks is growing.

Today 50% of the 1,300 types of clutch used in the UK and Europe are remanufactured by ClutchCo. The remaining 50% are imported from China. The clutches imported from China account for 80% of the total clutch sales volume. The remaining 20% of clutches are remanufactured in Nottingham by ClutchCo. This strategy allows the company to hold less stock of slower moving parts at the same time as allowing it to have full market coverage. ClutchCo accepts that its remanufacturing area may now be running at a loss. However it estimates this cost to be less than keeping the large stocks of slow moving parts that would be necessary if it was to import them from China.

It is estimated, although it has never been monitored, that it is possible to remanufacture a clutch up to six times. It is thought that this depends on the technique used to separate its constituent parts and the type of parts. Drilling out rivets using a CNC machine is thought to maintain core quality and hence increase the number of times a core can be remanufactured. Despite this CNC drilling has now been replaced by manual drilling. This is due to the increased flexibility required for remanufacturing such a diverse range of clutches in small batch sizes.

As an independent remanufacturer ClutchCo has found little cooperation from the OEMs of the products' it remanufactures. This is despite the legal obligation of the OEMs to cooperate. In order to develop a remanufacturing process, ClutchCo purchases OEM clutches and reverse engineers them. They have found this to be a more effective method than obtaining information from the OEMs directly. None of the clutches that are remanufactured by ClutchCo are supplied to OEM manufacturers.

An additional service that is offered by ClutchCo is a recondition and return service. This is for customers that have very old cars for which remanufactured or new clutches are not available. The clutch is sent to ClutchCo where only the required amount of work is carried out in order to bring it back to working order. This is done

in order to keep the cost to the customer as low as possible. It is thought that this service may not be profitable but is an important part of the business.

## **Clutch Parts**

Clutches consist of three main components. These are the Driven Plate, also known as the friction disk, the Pressure Plate, also known as the cover assembly and the release bearing. During the remanufacturing process the friction material on the friction disk and the bearing on the release bearing are always replaced. Other parts are inspected for wear and repaired or replaced as necessary.

## **Clutch Remanufacturing Process**

Core product is sent to the factory via two main routes. The main route is via a surcharge part return system. In order to purchase a remanufactured clutch the customer must supply the company with their old unit for subsequent remanufacturing. Not all of the clutches that are returned can be remanufactured so the remainder of core product required is purchased from core brokers.

After the cores arrive at the plant they are sorted. They are sorted by part type, against approved samples, and are visually inspected for any obvious damage which would make them unusable. The main fault inspectors are looking for is excessive wear to clutch diaphragms. Cores with excessive wear are only kept if they are slow moving products. This inspection procedure is time consuming and requires a high level of skill.

After inspection, the cores are formed into production batches and are stored in the warehouse.

Core product is collected from the warehouse and washed using a caustic solution. Sometimes the diaphragm is tested before the clutch is disassembled. The cover of the clutch is removed. Historically this was done using a CNC machine however now the rivets are drilled by hand.

The cover assembly and the pressure plate are then grit blasted to remove corrosion and to make the clutch look as new. The clutch pressure plate is then ground to give a new working surface. Special care is taken at this stage to remove as little material as possible.

After the grinding stage of the process the plate width is measured. Depending on the result of this measurement the plates are sorted into three routes as follows;

- Fit for use
- Requires compensating
- Scrap (usually only for excessive damage)

If the plate requires compensating then a ring is pressed into it to raise the fulcrum edge by approximately 0.5mm.

The clutch is then reassembled using cold headed rivets. Finally the reassembled clutch is tested for clamp load and clearance and then ink jet sprayed with its National part number and batch code.

## **Additional Points/Comments**

Some remanufacturers didn't understand the science behind clutches before they started to remanufacture them. This led to high failure rates of these 'remanufactured' clutches giving remanufacturing a bad name.

Changing a clutch on a car requires a large amount of labour (1-8 hours). Clutches are always supplied as sets of the three components so that they can all be changed at the same time.

Sadly remanufacturing in the UK is in a large decline. It is thought that the government could have done more to support it and potentially there should be a penalty for the use of new materials.



## **DefCo**

DefCo, which formed in the 1950s has carried out remanufacturing operations for many years. The remanufacturing business has only been separate since the early 90s. The remanufacturing business is high margin however the wider company does not seem to understand the importance of the remanufacturing division. This is despite it having some of the top 5 products manufactured by DefCo. The low profile and lack of understanding of the remanufacturing side of the business makes it difficult to gain investment from the wider organisation.

DefCo's remanufacturing business processes a huge range of products. It is the OEM for some but not all of these products. These come from manufacturing contracts which it has held in the past. It also competes for specific remanufacturing tasks, in one such competition the contract was signed by a different firm at a price that would have meant a loss at DefCo. There are 3 or 4 rolling contracts that give base load to the remanufacturing business. These include specific jobs for companies in the aerospace industry. A final stream of products comes from the logistics part of their parent company. This holds the contract for disposal of all end of life equipment from part of the MOD. These customers have high and specific quality standards for equipment they send for remanufacture.

## **The Remanufacturing Process**

If necessary the item is cleaned. The exact process used depends on the nature of the item. A mechanical survey is carried out to establish the condition of the item and to identify which parts are broken or missing. This is used to give a broad description of the faults with the item. If necessary an electrical test is carried out to access the functionality of the item. Failing components are identified using standard procedures and technical details of the product from its manufacturer. A BOM is produced from the survey and testing procedure and a quote is given to the customer for the job. The time to carry out a repair is based on historical data for similar jobs and if necessary calculated from the stages involved in the task. This is calculated by highly experienced assessors and is used to calculate the labour cost for the job. If the quote is accepted by the customer then the required parts are procured and the required work is carried out. For the MOD an item is usually considered to be beyond economical repair if the cost of repair is 60-70% of the cost of new.

After it is repaired the item is tested and inspected before being returned to the customer.

## **Problems with Remanufacturing**

Intellectual property rights restrict what can be repaired and by whom. DefCo will always seek permission from the OEM of the product before carrying out any repairs or fault analysis. A payment is normally required before the process can be started. Typically the OEM of the product might prefer to carry out the work itself.

The high levels of skill and different knowledge that is required when compared with forward manufacturing causes difficulties. This is especially the case for the inspection and fault finding stages of the process.

It was stated that remanufacturing and repair of this type of equipment is a high margin business if it is run well. However the individual order values are low and forecasting is difficult. This in conjunction with its dirty blue collar image means that remanufacturing is not given all of the support and investment it deserves. It is also highly dependent on government policy which gives a feast or famine scenario.

The decision to scrap or repair an item is further complicated by the problems associated with determining the value of a 'new' item when it is no longer manufactured. For this reason the decision is not normally made based on cost alone.

## **GearCo**

GearCo is a remanufacturer of automotive drive trains based in the UK. They remanufacture engines, transmissions and gearboxes as an official remanufacturer for most major automotive manufacturers including Ford, Mitsubishi and General Motors. They believe themselves to be the biggest remanufacturer of gearboxes in Europe processing some 20,000 units per year. They work to the TS16949 quality standards and the ISO14001 environmental standards. There are other companies that recondition parts however this is not to the same quality standard as remanufacture and it is not carried out working with the OEMs.

Automotive manufacturers aim to be able to supply spare parts for 10-15 years after full production has ceased. When a remanufactured item is required by a customer they must return their faulty core to GearCo who then supply a remanufactured item. It can take up to 6 hours to remanufacture a gearbox however the lead time for the supply to a customer is between 48 hours and 7 days. Because of this lead time, cores for remanufacture are provided from stock and it is not usually the case that the item returned to the customer is the same one as was returned as core. After remanufacturing a returned item, it is expected to be as reliable as a new product and the OEM customer will offer a warranty as good as that given for new products.

Most core material is supplied by the OEM customer and is treated as consigned material, remaining the property of the supplier until remanufacturing is complete. The core storage facility is owned and operated by GearCo and is regularly audited by the OEM companies.

GearCo remanufacture a staggering diversity of products. They hold Bills of Material for more than 3000 assemblies but “only” some 500 are in regular production. There can be up to 50 different part numbers within one gearbox family and the exact part number and hence the Bill of material required for the unit being remanufactured is often not known until it has been disassembled – this is part of the expertise or “black-art” of the business.

## **Process of Setting up a Business Agreement**

An OEM typically approaches GearCo with a new item they wish to be remanufactured in the future. Highly skilled inspectors make an estimate of the failure rates of components within the item. These are used along with their cost of replacement in order to estimate the cost of remanufacture for that product. Typically the highest replacement rates are for bearings at 100% and the lowest for nuts and bolts, typically 5%. If the cost is accepted by the OEM then they sign a contract and form a business agreement.

Initial failures are replaced with new items in order to establish a seed stock of cores. On a monthly basis the actual failure rates of the items are compared with the estimates to ensure the process is running as planned.

When the decision is made to scrap or process a core the cost of remanufacture is not used directly. The number of part replacements that would make remanufacture uneconomical is known in advance. Any core that exceeds this is rejected. If demand exists for other parts from the core then it will still be disassembled. Overall around 90% of cores that are sent to GearCo are remanufactured. If required 100% of cores could be used. On occasions when more cores of a particular type are supplied than there is a need for a process of over stripping is used in order to reduce costs. For example if 100 remanufactured gearboxes are required then 120 may be disassembled.

There are also occasions where a quote is given for a specific job. An example of this was given where an OEM requested a quote to remanufacture a number of gearboxes that had been left outside exposed to the elements and had started to rust.

## **The Remanufacturing Process**

A core is taken from the store when an order is received. An initial inspection is made for obvious damage which would make the core uneconomical to repair eg a cracked case. The core is disassembled and cleaned using a three stage cleaning process. A glass bead blast is used as well as a high pressure and low pressure chemical clean. Parts that are always replaced, eg bearings, are removed and scrapped other parts are inspected for reuse potential. The reason for failure of a returned core is not always obvious. Experienced inspectors assess parts against criteria set in conjunction with the OEMs. For some parts a decision is made based on measurements of the item and for others a decision is made on the basis of the amount of wear it has experienced. This can be used to estimate the amount of life remaining in the part. There are no parts at all that are never replaced.

Some of the smaller parts are removed from the core and sent through a separate cleaning and inspection procedure.

The main parts are placed in a tray together. An Inspector utilises a computer based system to establish which parts are required for replacement and to generate a stores order for them and it is at this point the failed parts are removed and scrapped. The computer system generates a label containing details of the parts required. These are then collected from the store and placed with the recovered parts. This collection of parts is then sent to an assembly bench where the unit is assembled by one individual in a single stage build.

All of the replacement parts that are used are supplied by the OEMs or OEM approved suppliers. Non-OEM parts could be used however the remanufactured gearbox would not be able to carry a full OEM warranty. Some parts are only available from the OEMs.

Once assembled the unit is put through a testing procedure developed in conjunction with the OEM. The gearboxes are run with and without load and analysed for noise and operation. Acceptable limits are set in conjunction with the OEM. 100% of the units produced are inspected in this way.

New units can also be produced by GearCo as required by the customer. These are built in the same way as remanufactured units but using 100% new parts. All assembly is done by hand in a single stage, this is due to the amount of flexibility that is required in the process.

## **Problems Identified by GearCo**

The improving of new products mean that the need for remanufacture may reduce in the future and the ELV directive currently lacks sufficient impetus to increase the amount of remanufacturing. However, remanufacturing is now being recognised as a professional business maximising the use of valuable resources and current initiatives are expected to benefit the industry.

Costs of manufacturing and compliance with environmental regulation are higher within the UK than in many of the low cost, developing territories.

The RSMS regulations that govern the use of certain materials will make remanufacturing more difficult in the future. These regulations will not be an issue for the independent remanufacturers since they don't have detailed information about the materials with which they are working.

A comment was made that last time buy decisions were never made correctly. The level of skills required to carry out high quality remanufacturing was also cited as being a problem.

## **PCCo**

PCCo was established in 1980 by a Swiss owned leasing company. The leasing company used the competencies it had gained from remarking end of lease equipment to set up the new computer remarketing company. In 2004 the company was sold and formed a separate entity.

The mission of PCCo is to extend the life of office equipment. They offer a wide range of services collection and auditing of unwanted equipment to the supply and installation of refurbished equipment.

95% of the time they are hired in order to dispose of old equipment. The vast majority of this, about 99%, is IT equipment with the majority being laptop and desktop computers.

PCCo is hired to dispose of equipment by leasing companies and other businesses and often buys computers in from other sources in order to satisfy demand for its refurbished computers.

75% of the equipment it remarkets is sold to business customers. These business customers are typically SMEs. This is thought to be due to the small amounts they require and the lower purchase cost when compared to new equipment.

Equipment is sold with a 14 day 'no quibble' guarantee and a 90 day full swap-out warrantee against failure. This warrantee can be extended as far as required at a cost to the customer. Despite this very liberal returns policy, only 2% of equipment supplied to customers is returned. This shows that it is very high quality and as reliable as new equipment. Customers are very happy with the equipment supplied and many give repeat business.

Not all of the equipment that PCCo is sent is refurbished and resold. They offer services to clients including auditing, testing and data wiping as required.

## **The Refurbishing Process**

Items that are deemed to be unmarketable are separated from the batch of equipment and are sent directly to a recycler. Items for which this is done currently include 15" CRT monitors.

The remaining items are sent to the refurbishing facility. On arrival a batch number is allocated to the equipment and a unique tracking number is given to each piece of equipment. This enables the equipment to be tracked through its time in the refurbishing area and provides an audit trail in case the item is returned or other information such as evidence of data wiping is required.

Information regarding the item type, manufacturer and model number is stored against the tracking number at this stage.

The batch is then sent to the workshop where it is processed. Equipment is connected to a network which automatically audits and tests it. The network stores data about the equipment, carries out data erasure in accordance with the UK government standard and creates a record of the wipe. Software is used to carry out a fault diagnosis of the equipment. If a hard drive is found to be defective it is removed and destroyed at this stage.

The majority of equipment is found to be working. The exact amount varies depending on its source. A table of these details is shown below;

<b>Equipment Source</b>	<b>% Working</b>
Bought from Market	100%
Leasing Returns	90%
Corporate Discards	60-70%

A visual inspection is made and the equipment is cleaned as necessary. Depending on contractual requirements the equipment is returned to the client or is passed through to the next stage of the process.

Information collected during the diagnostic ‘bench’ test is used in order to determine the fate of the equipment. A triage principal is used to sort the equipment into 3 streams. These are reuse, recycle and carry out further tests. Diagnostic information, collected during the bench test, is then used in order to calculate a repair cost for the equipment. This consists of the cost of parts and labour required to process the equipment in the necessary way. Overheads are added to this using an absorption rate calculated on a monthly basis. A profit margin is added to this and compared with the market value of the item. If it is estimated that processing and reselling the item will be profitable then it is processed, otherwise it is sent for materials recycling.

After the decision is made to continue processing an item then it is repaired as necessary. Where a software license exists for the item then the applicable operating system is reloaded onto it. An electrical safety test is carried out, the item is cleaned and repacked (including a system restore disk) and it is sent to the warehouse for storage until it is sold. At this point the equipment is made available for sale through the website and it is marketed directly to customers.

### **Other Points Raised During Meeting**

PCCo feel that the WEEE directive is a good thing as it will eliminate ‘skipping’ of old equipment and it should reduce the amount of cowboys in the computer reuse industry. PCCo thinks that it could have done a lot more for Reuse and that we’re still waiting for this to happen.

It is worried about the ‘export’ of used IT equipment to developing countries as it may not be treated correctly at its end of life.

It was stated that there is a need to move away from a gadget society and towards proportionate computing – the right tool for the right job.

PCCo finds itself short of equipment for remarketing. It buys used computers from the open market as tested and then processes them according to its normal procedures. It predicts how many it will require to balance demand using an inventory matrix.

PCCo is concerned about consumers’ perceptions of refurbished equipment. It is thought that they see it as inferior to new equipment. A case was discussed in which PCCo had been short listed to supply equipment to a local authority only to be rejected due to the equipment being 2<sup>nd</sup> hand. PCCo feels that the government should take a lead in use of refurbished equipment to boost consumer confidence in the products. PCCo feels that a new term to describe remanufactured or refurbished equipment would be useful to increase consumer confidence.

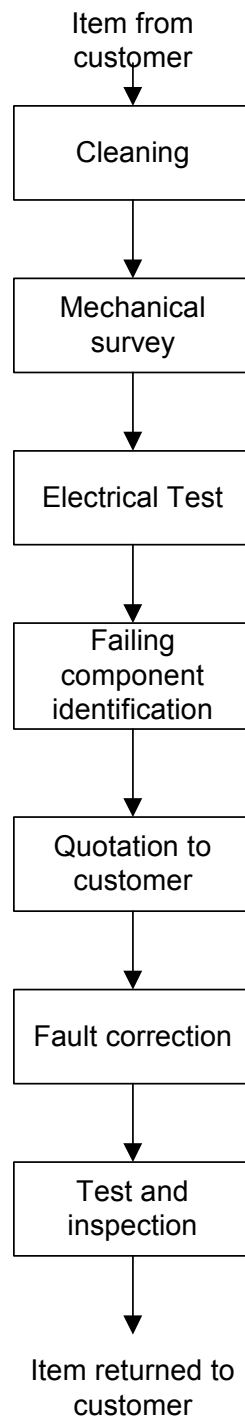
The problem of what to do with used IT equipment has been a problem since it has been produced. OEMs don’t want used equipment to be sold as it bears their name. PCCo is concerned that if they run a certification scheme then the ‘bar’ may be set too high for remanufacturers. PCCo find it difficult to obtain information

from some manufacturers that would assist the re-manufacturing process e.g. spare part numbers. They are keen for customers to buy new equipment.

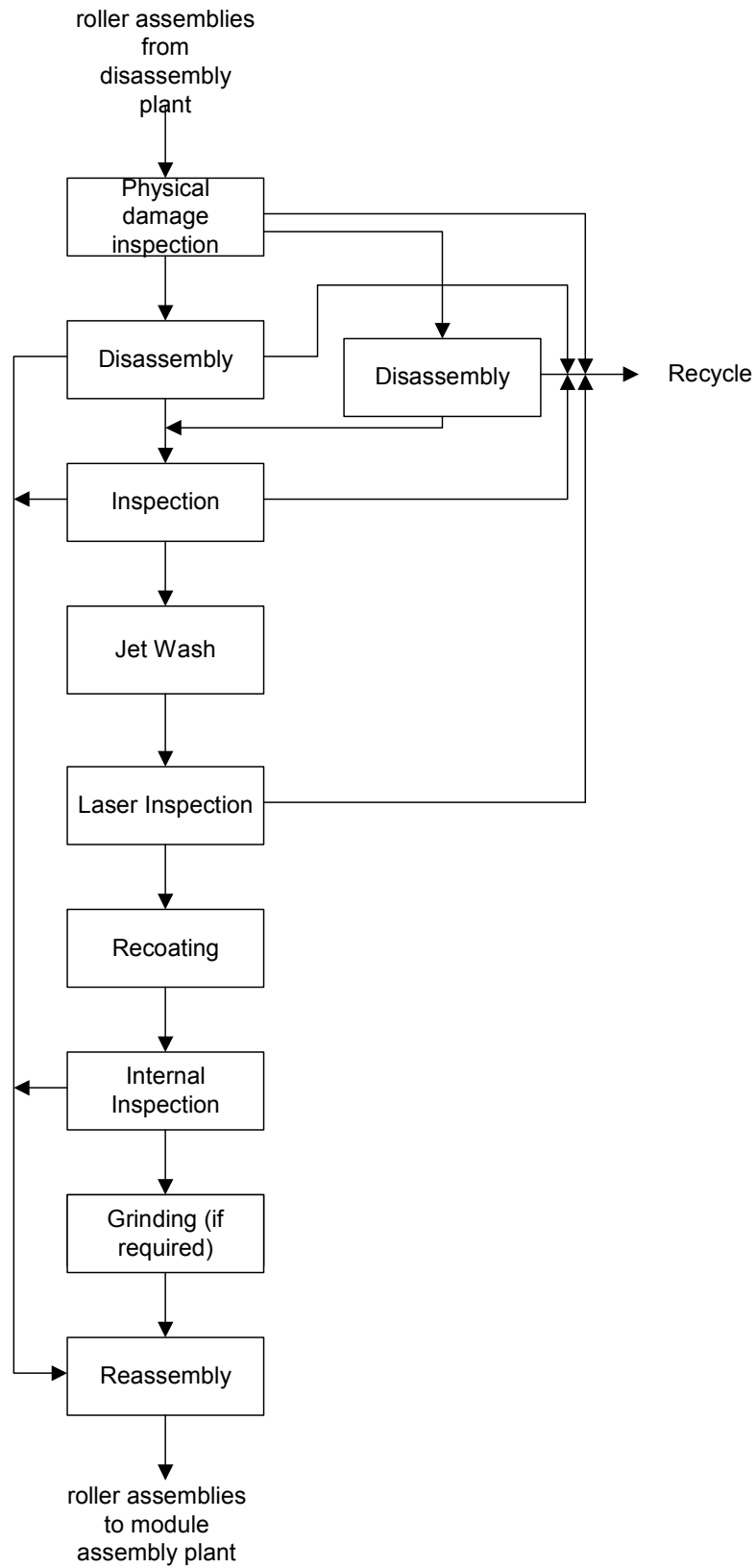
Operating system providers also make it difficult to reuse equipment through their software licensing rules and lack of support for old operating systems. Installing Linux on remarketed machines is an option however there is a cost associated with it and this service is not used often.

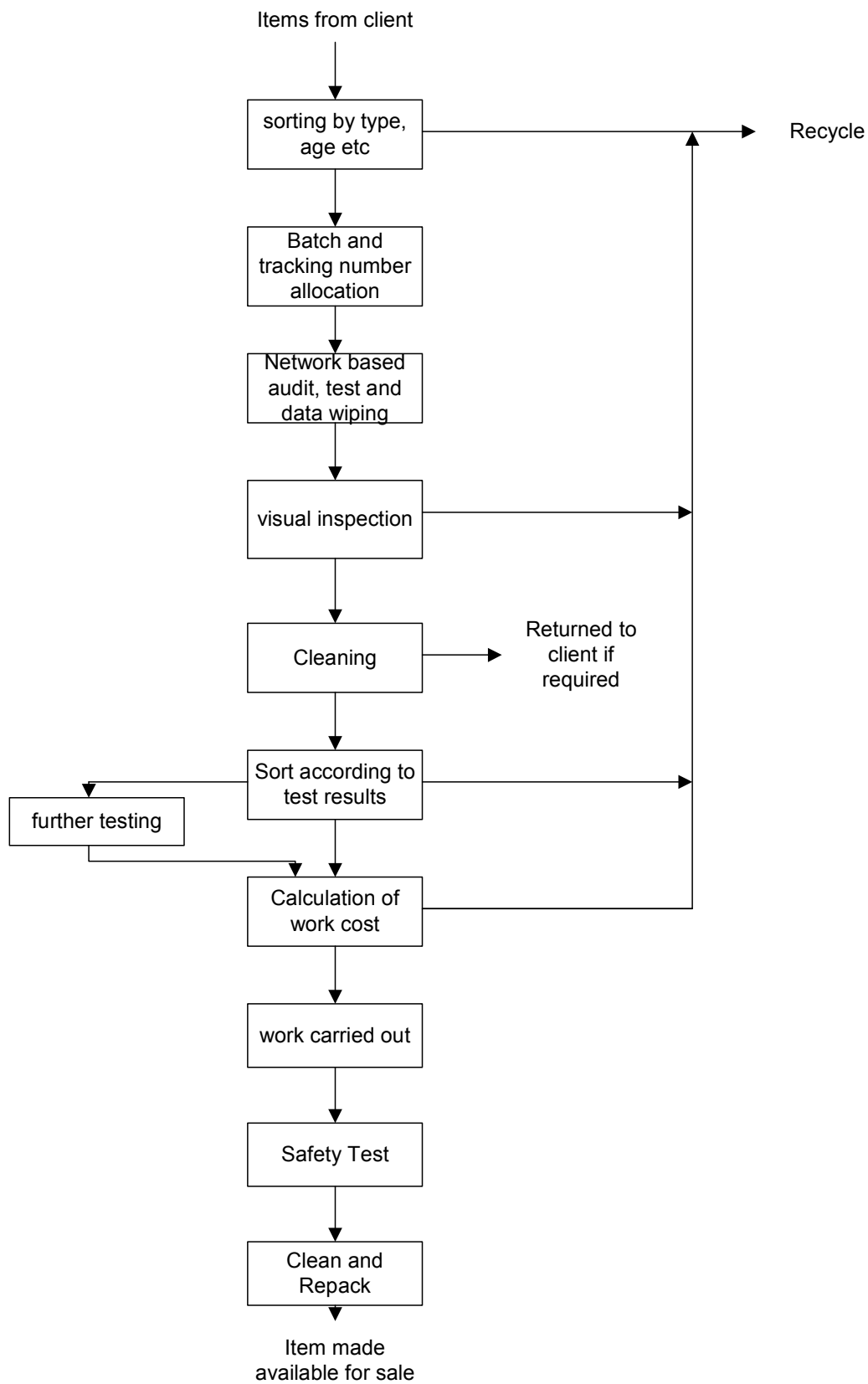
## Appendix F. Case Study Remanufacturing Process Flowcharts

### *DefCo*

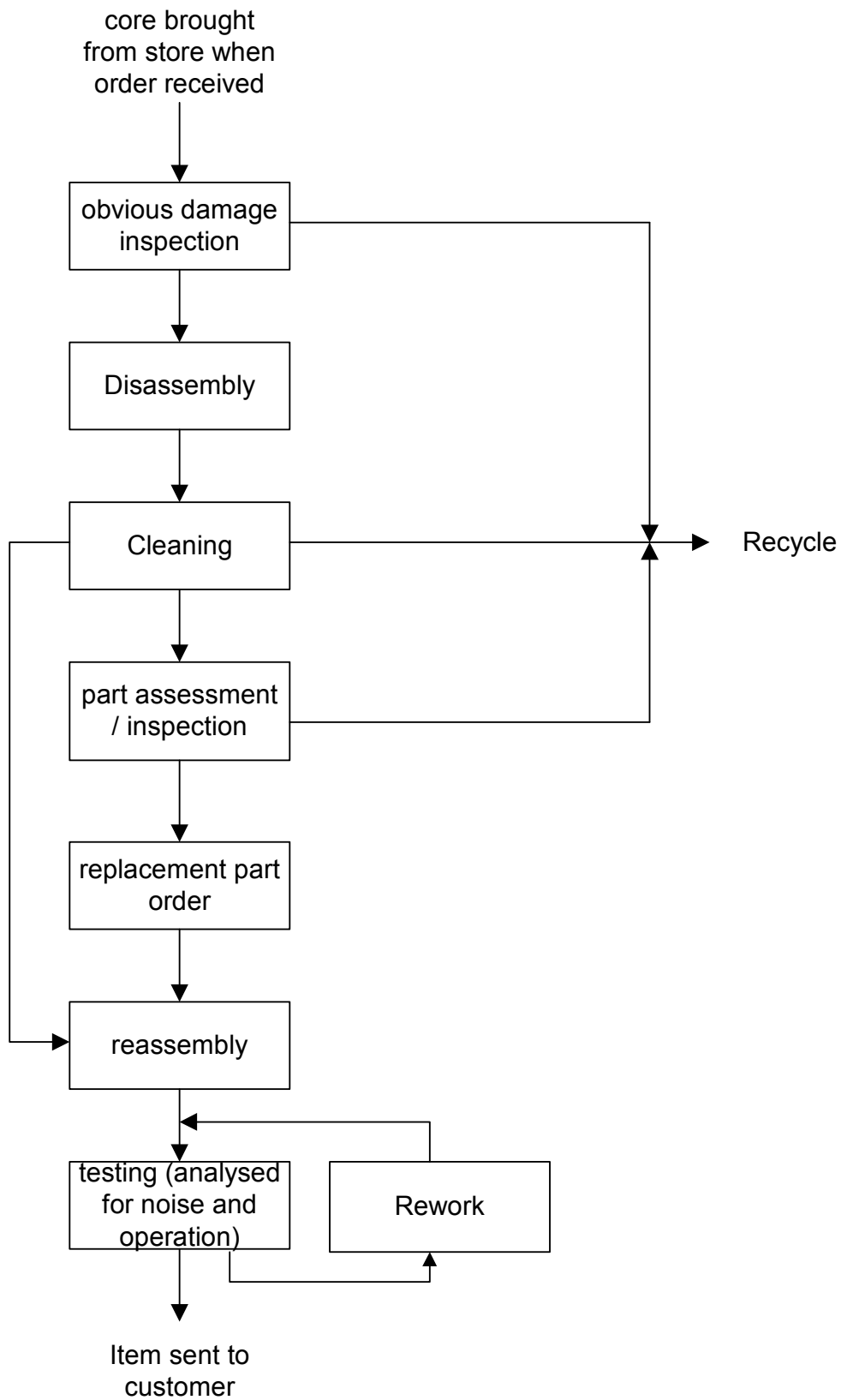


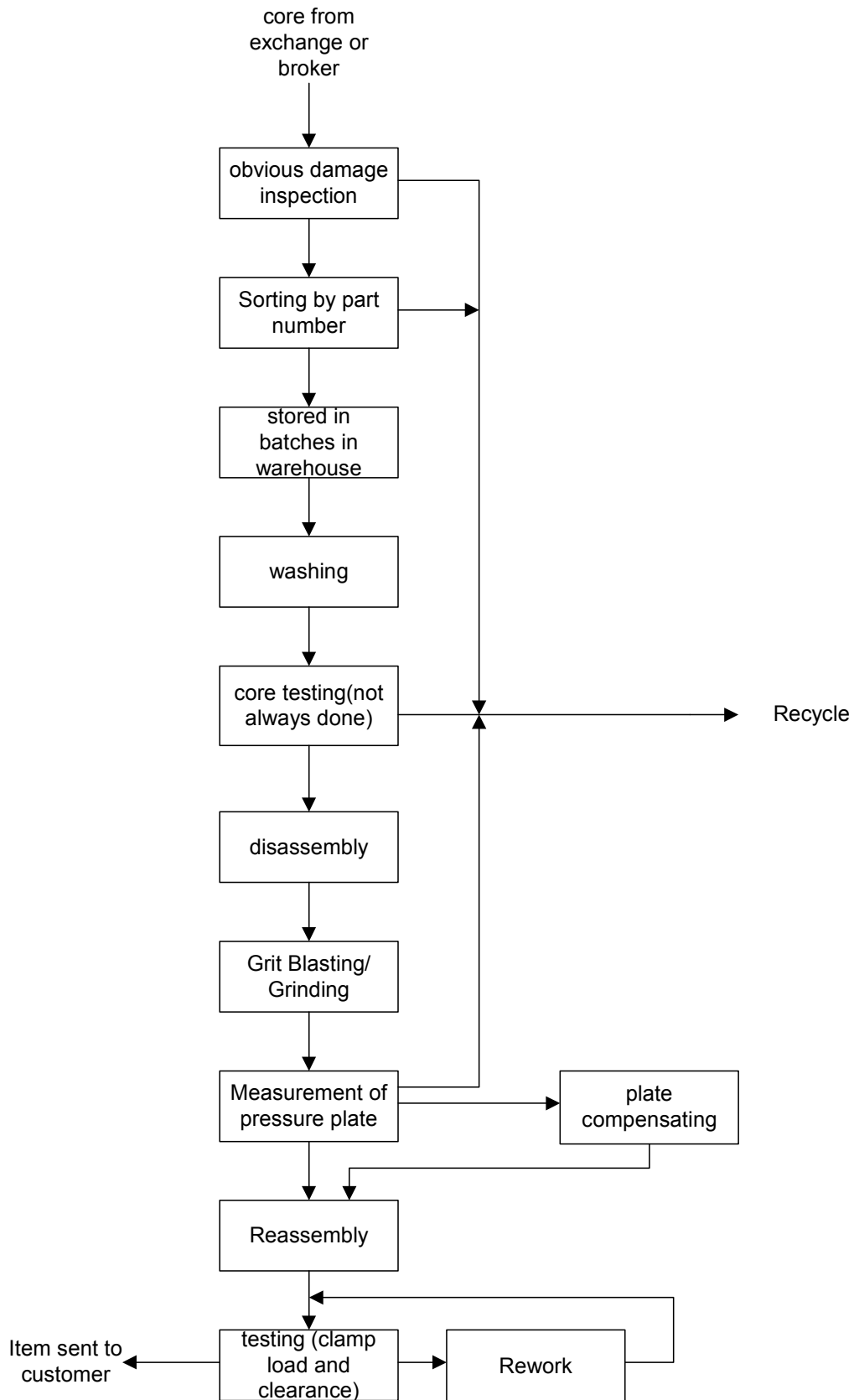




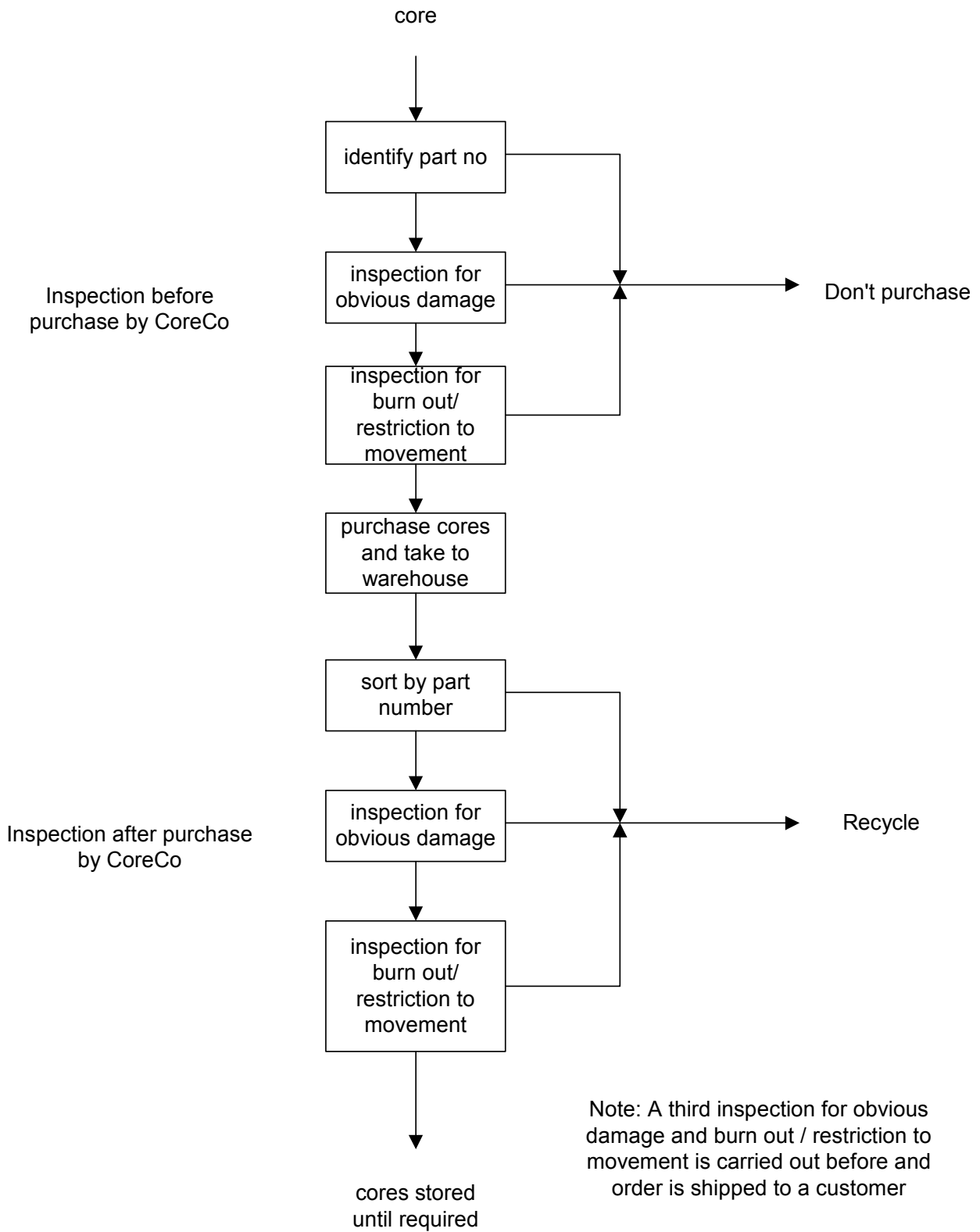


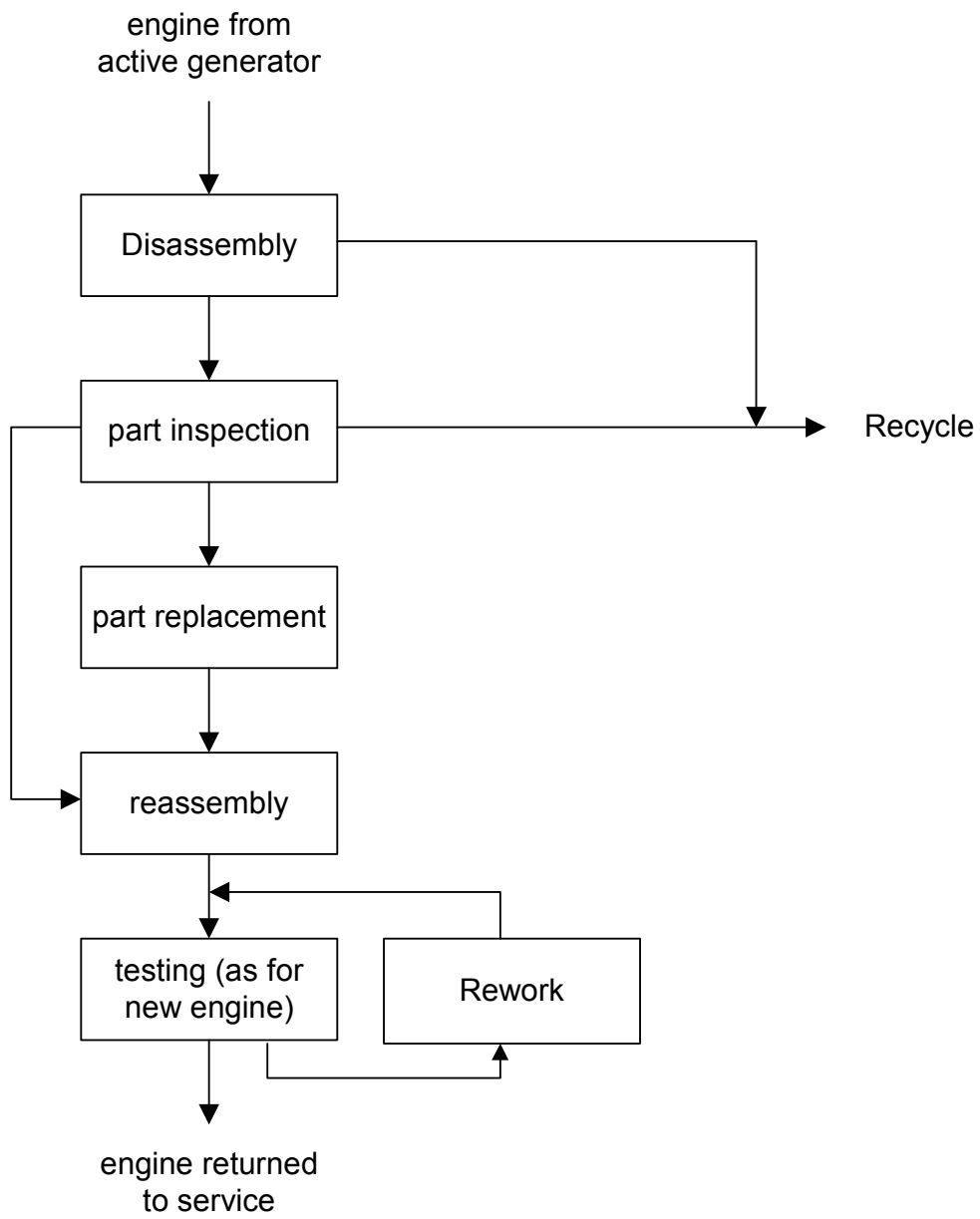
## GearCo



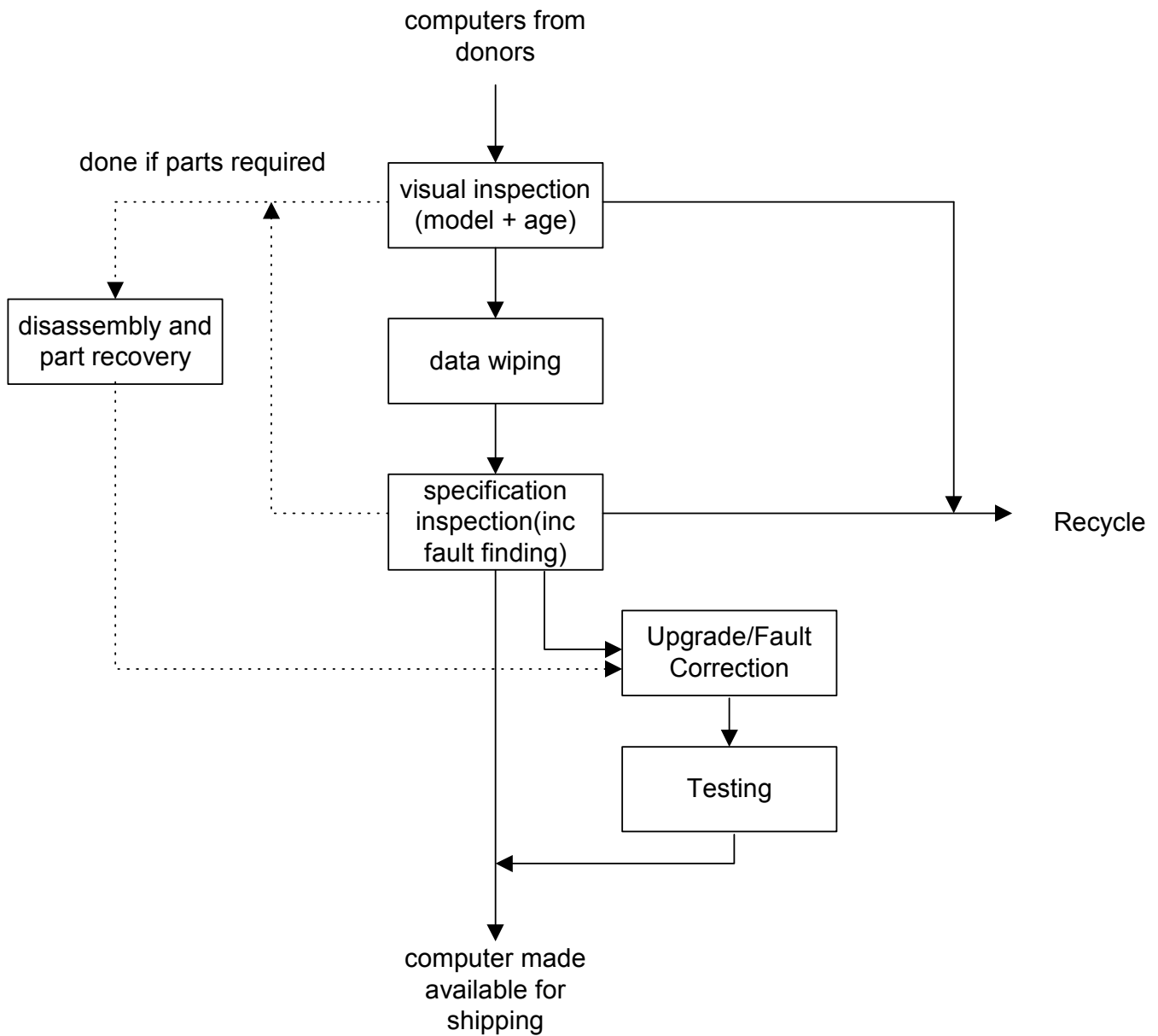


## CoreCo

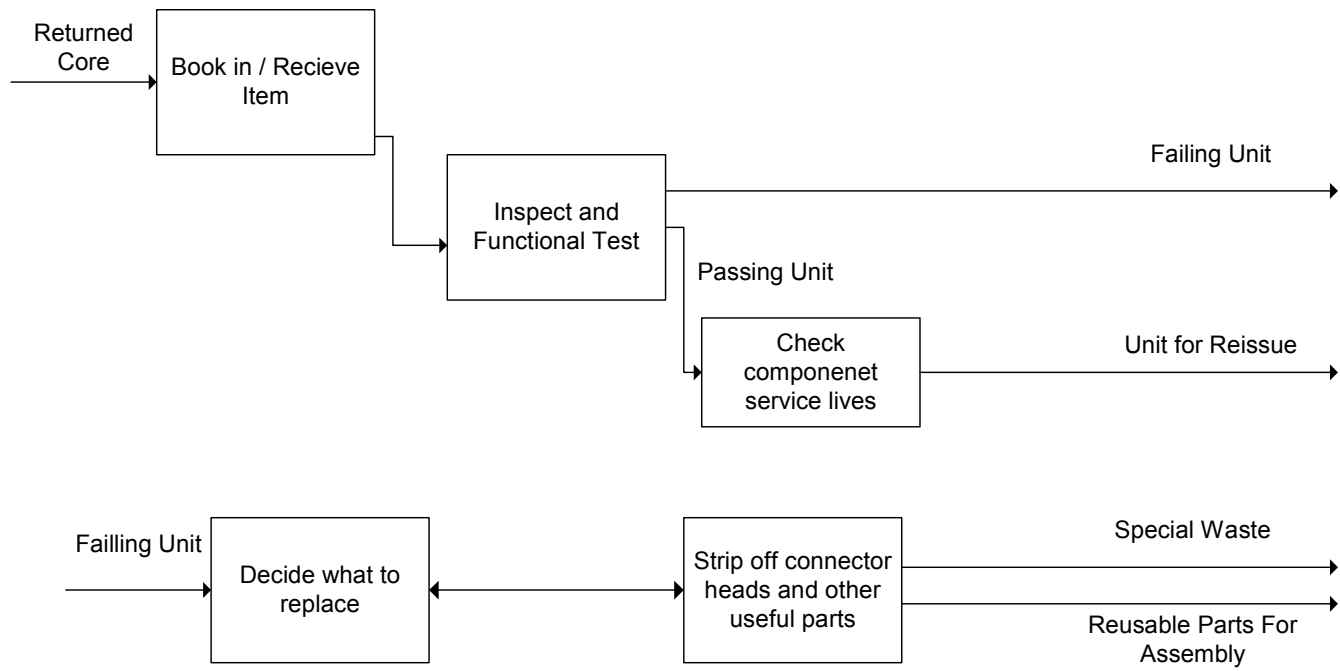




## CompCo

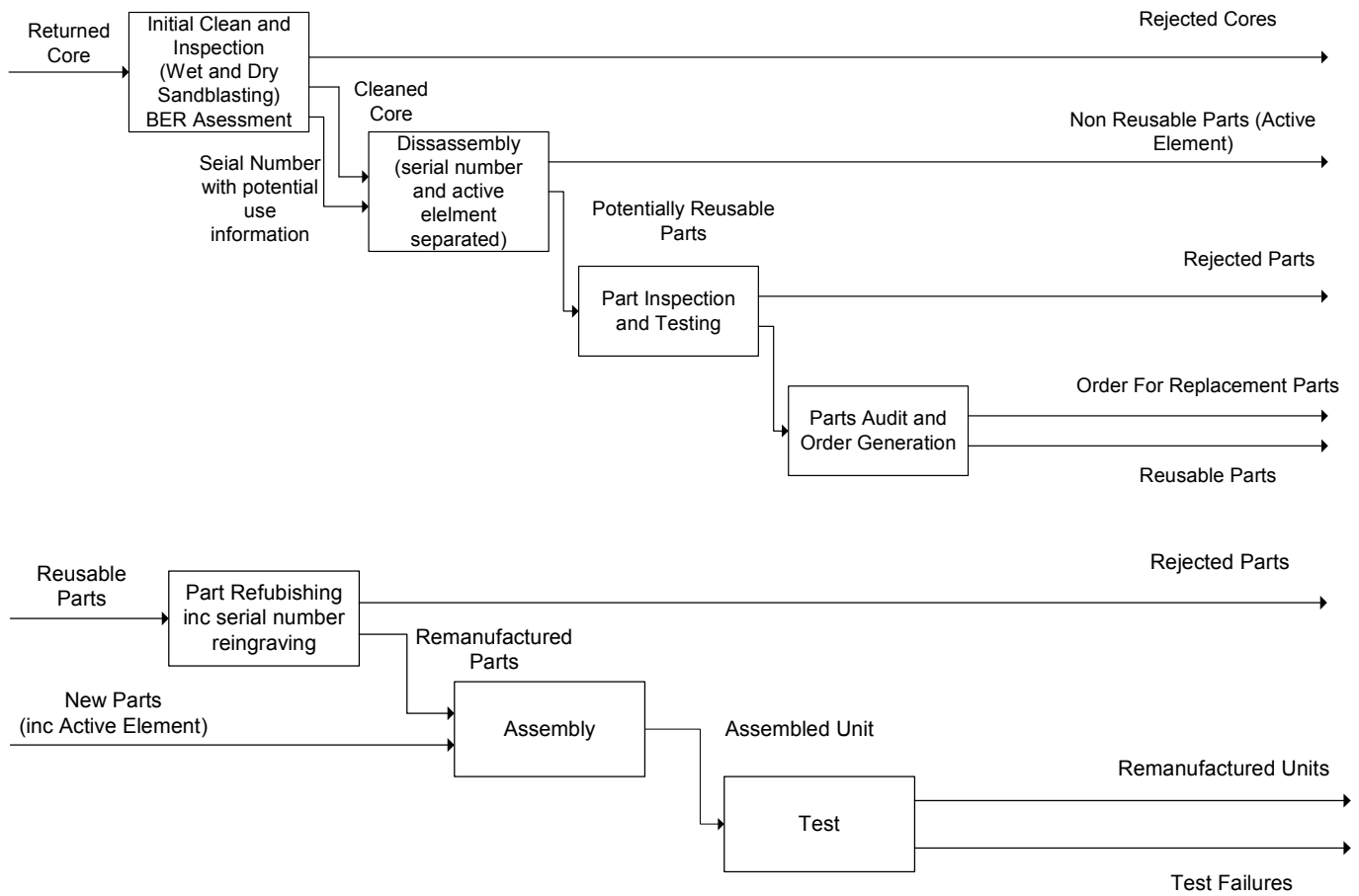


## ***MilCo – Product A***





## MilCo – Product B



## Appendix G. Model Descriptions

### Remanufacturing Inspection Models

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#### **Introduction**

Case studies were carried out with a number of companies engaged in remanufacturing in the UK. Some of the cases remanufacture a large volume of products and operate in a highly competitive market while others remanufacture smaller numbers of items and are known for their expertise and competency. Many of the cases studied were not found to describe their process as remanufacturing. For the purposes of this research the process was considered to be remanufacturing if it met the definition developed by King, Burgess et al. (2006) and regularly quoted by Oakdene Hollins. It defines a remanufacturing process as follows;

*“Remanufacturing is the only process where used products are brought at least to Original Equipment Manufacturer (OEM) performance specification from the customer’s perspective and, at the same time, are given warranties that are equal to those of equivalent new products”*

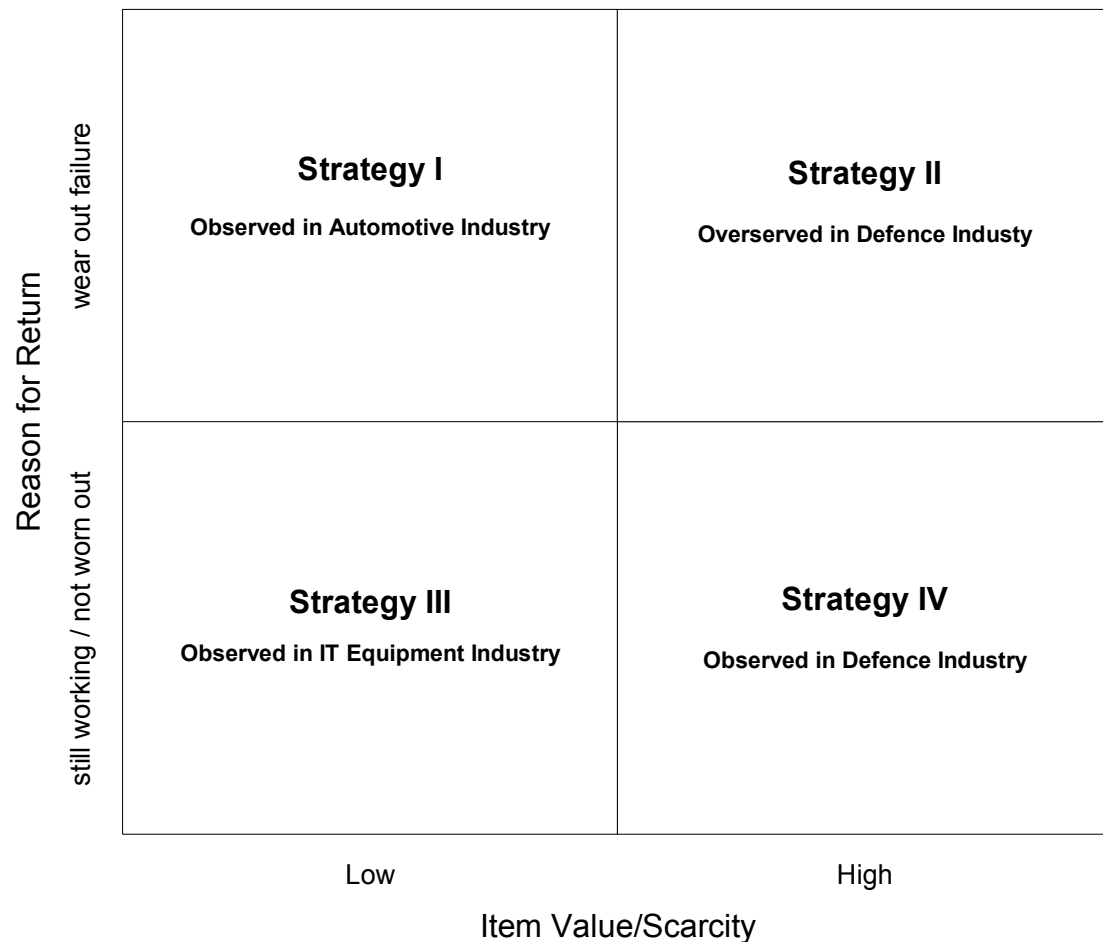
The main objective of these case studies was to gain a detailed insight into the role and process of inspection carried out by remanufacturing firms. It aimed to establish the objectives of inspection and testing at all stages of the remanufacturing process and the differences in the methods used in processes run by different organisations.

For the purpose of this research the word core is used interchangeable with returned product. ie an item that is available for remanufacturing. This may be an item that is returned because it has broken down, worn out or returned from a user following a leasing period.

#### **Methods Observed**

There were many differences found in the way the case study companies carry out their inspection and testing processes. Many of the differences exist for product specific reasons. This may be due to constraints from the product’s OEM, customer quality demands and time constraints. It is thought probable that methods used in some sectors can be successfully replicated in others.

The following diagram shows the main strategies that were observed in the case study companies.



*Figure 1 - Core Remanufacturing Decision Making Process Strategic Framework*

It can be seen from Figure 1 that the main reasons for the different strategies used by the case studies were due to core value and type of core. Core value can be used interchangeably with scarcity of core. If cores are relatively cheap, disposal is an effective way of increasing the reliability of the population as a whole. If cores are expensive they must be processed almost regardless of cost. In the case of low value cores there is often a new alternative that can be purchased in its place.

If cores are scarce the situation is very different. It is sometimes the case in the defence industry that it is impossible to get a new unit made at any cost. The alternative to a remanufactured product is to upgrade a wider system to accept a new unit. Although this leads to a clear cost limit, this is often so high that it is not considered during the remanufacturing inspection process itself. If it is feasible for a product to be remanufactured, and new products cannot be made, then it will be almost certainly be done regardless of cost.

The reason for the return of a core is the second key variable that was identified. The reliability of a new, fully working product would not be increased by complete disassembly and reassembly of it. In the same way, a product with a large life expectancy does not need to be disassembled to be remanufactured so long as it is found to be fully working or if a minor fault is repaired. In contrast products that have failed due to a worn part need to be carefully inspected on a part level to insure that other components aren't also close to failure.

## Generic Inspection Procedures in Remanufacturing Processes

A generic inspection procedure was developed from the case studies using the IDEF0 modelling standard. This was then compared with each of the cases in turn. Notes from case study visits were used along with product characteristics to explain the differences in the processes.

In the cases that were studies three key areas of inspection in were found each carried out at a different stage in the remanufacturing processes. These were:

- Core inspection/testing
- Part inspection/testing
- Final product inspection/testing

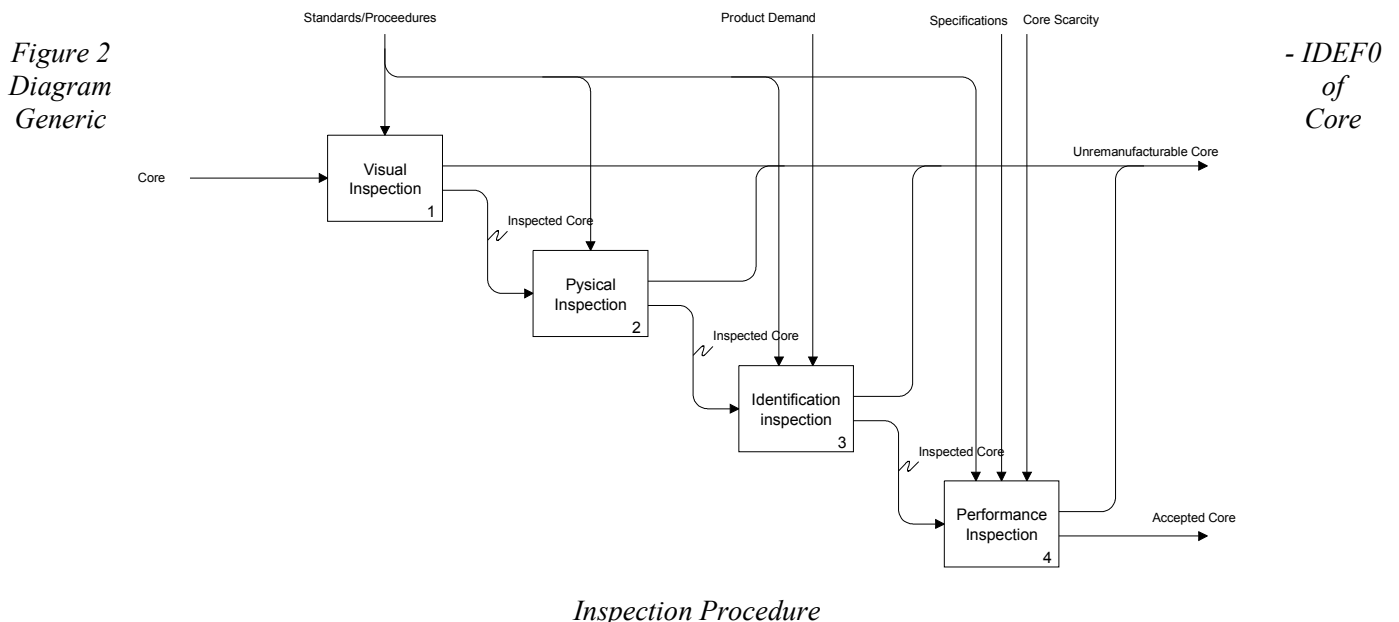
Each of the stages of inspection has different objectives. The objective of core inspection and testing is to remove cores that will be uneconomical or impossible to remanufacture. This improves the reliability of the population of items that are produced and ensures that cores that are uneconomical to remanufacture do not enter the process.

The second stage of inspection is carried out once the core has been disassembled. Part inspection and testing aims to remove non reusable components from the product in order to increase its reliability once it is reassembled. These parts may be non reusable because they have already failed, or are likely to fail within the next product life.

The final product inspection stage is carried out to insure that the products are in full working order before they are shipped. Products that fail this stage are reworked before being retested and sold.

### Core Inspection

Cores are usually inspected as soon as they arrive at the remanufacturing facility. The following figure shows the details of how this inspection is carried out.



The figure shows the four main tasks in the core acceptance procedure that were identified. The first is a visual inspection. This is carried out simply through looking at a core and deciding if it has obvious major

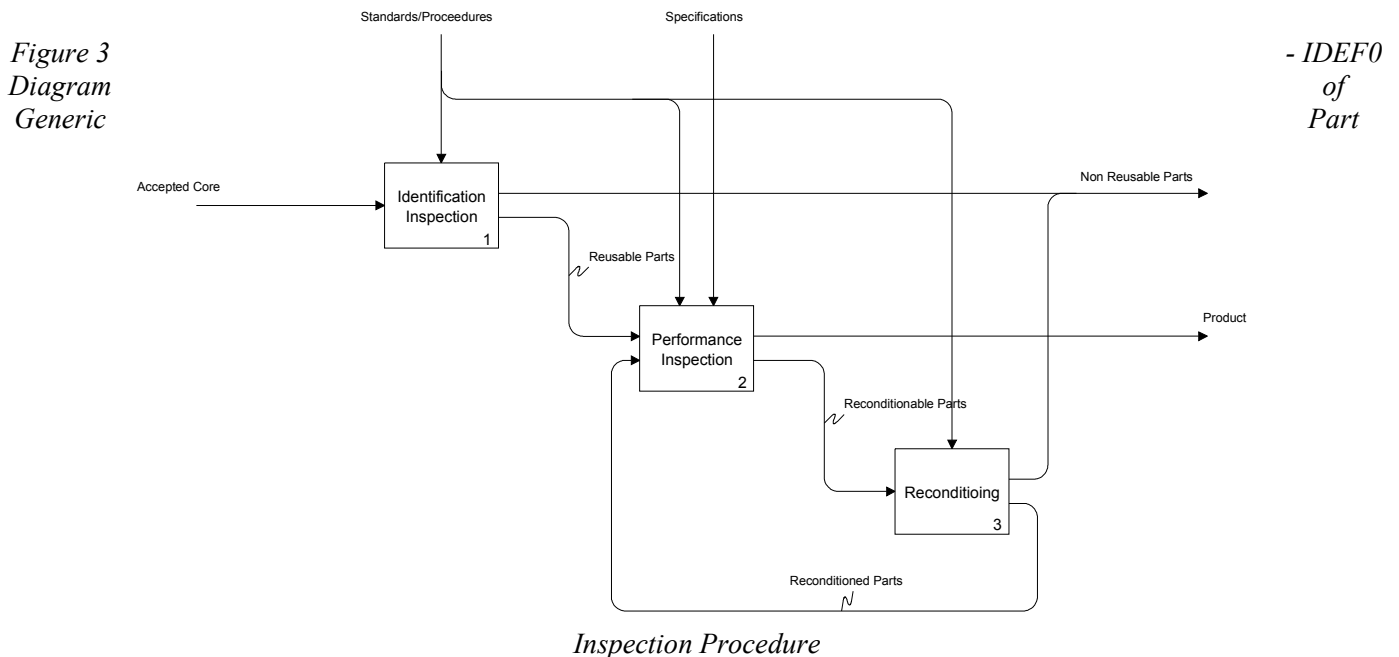
damage which would make it unremanufacturable. An example of products that would be rejected at this stage would be products that have been crushed during transit to the remanufacturing facility.

Cores that have no obvious signs of major damage are subjected to the second test in the procedure. This has been described in Figure 2 as the physical inspection. Again this is still done manually but the actual process varies depending on the core being inspected. For automotive components two main methods are commonly used. The first is to attempt to rotate any part of the product that should normally move and the second to smell electrical components to test for burn out. Cores that fail this test are sent for recycling and/or disposal.

The third stage of the process is to identify the part type and part number of the core. This is used in order to estimate the demand for and value of the product after it has been remanufactured. Cores for which there is no demand are disposed of at this stage. The fourth and final task within the core acceptance procedure aims to access the performance of the core. This is usually done using test rigs specifically designed for the procedure. The standards the product must meet are set by industry bodies, international standards or the remanufacturing firm themselves. The aim of this process is twofold; firstly to establish if the core is economical to process and secondly to establish if the finished product is likely to conform to specifications once it has been remanufactured.

## Part Inspection/Testing

Once cores have passed the core inspection and testing procedure they are sent for remanufacture. Firstly the cores are disassembled and extensively cleaned. After this they are passed to the second set of the inspections and tests. The process diagram for this process is shown in *Figure 3*

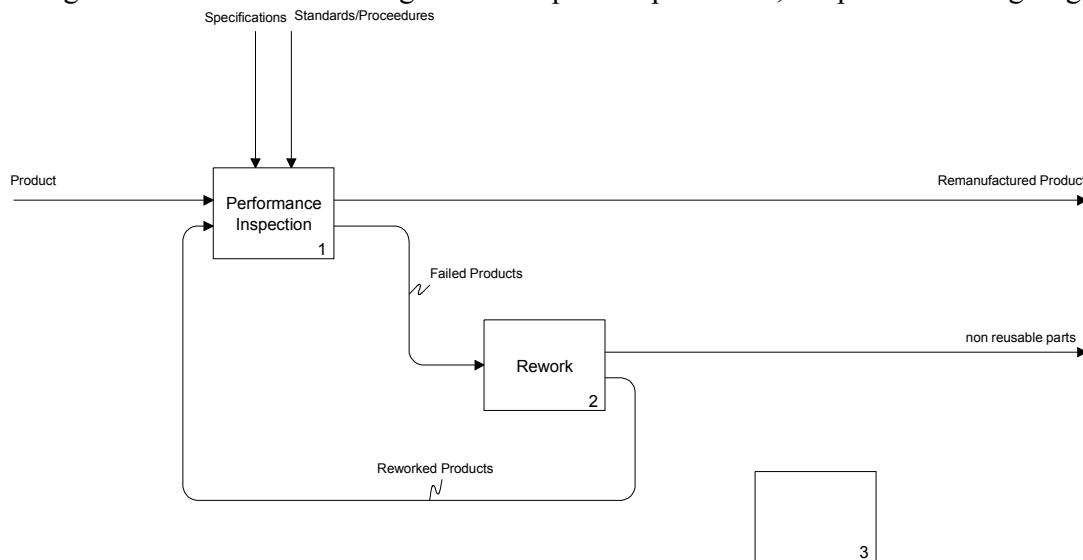


It can be seen from the diagram that some of the tasks are similar to those carried out the core level. Firstly the part is identified, if, according to company procedures, it is a part that is always replaced then it is discarded immediately. These are usually wear components and are often the reason for previous user discarding the product. Parts that are sometimes reused are sent through a performance inspection process.

Typical activities in this process include measurement and leakage testing. If they are found to not conform with required specifications then they are either discarded or reconditioned. After reconditioning parts are inspected once more for performance in order to ensure they meet requirements.

## Final Product Inspection/Testing

Once the quality of parts has been proven, they are passed through to the next stage of the remanufacturing process. Additional parts, either new or reconditioned from other sources, are used to replace the ones discarded in the previous inspection stage and the product is reassembled. Once it is reassembled it is passed through to the third and final stage of the inspection procedure, the product testing stage.



*Figure 4 - IDEF0  
Diagram of Generic  
Final Product  
Inspection  
Procedure*

It can be seen that performance inspection is once again the key part of this inspection and testing procedure. This is the final stage at which the reliability of the

final product can be estimated and/or ensured. The process and standards carried out during the performance inspection are different for each product. In the case of OEM approved remanufacturers these are developed with the involvement of the OEM for the product concerned. Products which fail the performance inspection are reworked and retested before they are sold.

## **Framework Process Diagrams**

This generic framework was modified for each of the sectors shown in *Figure 1*. This section will outline the major differences between the process diagrams. A complete set of diagrams for each strategy can be found in the appendix.

### **Strategy I**

This strategy includes all of the processes shown in the generic process. A cost based decision is used to identify the most economical cores for remanufacturing. A large part of this is an assessment of the amount of work required to process the core. This is done through simple tasks such as testing to see if relevant parts move smoothly. Once accepted cores are fully disassembled and parts are inspected. All cores are processed in the same way. This has been described in the literature as the ‘Bang Bang’ approach.

### **Strategy II**

When cores are scarce less emphasis is put on core inspection. The aim of this process is to establish if it is possible to remanufacture a given core rather than if it is economical. This is usually done at a core level using a simple visual inspection. It is sometimes the case that an individual core will be remanufactured at a loss if that means the maximum lead time for a given contract is not exceeded. Once considered feasible all cores are disassembled and inspected following a process similar to Strategy I.

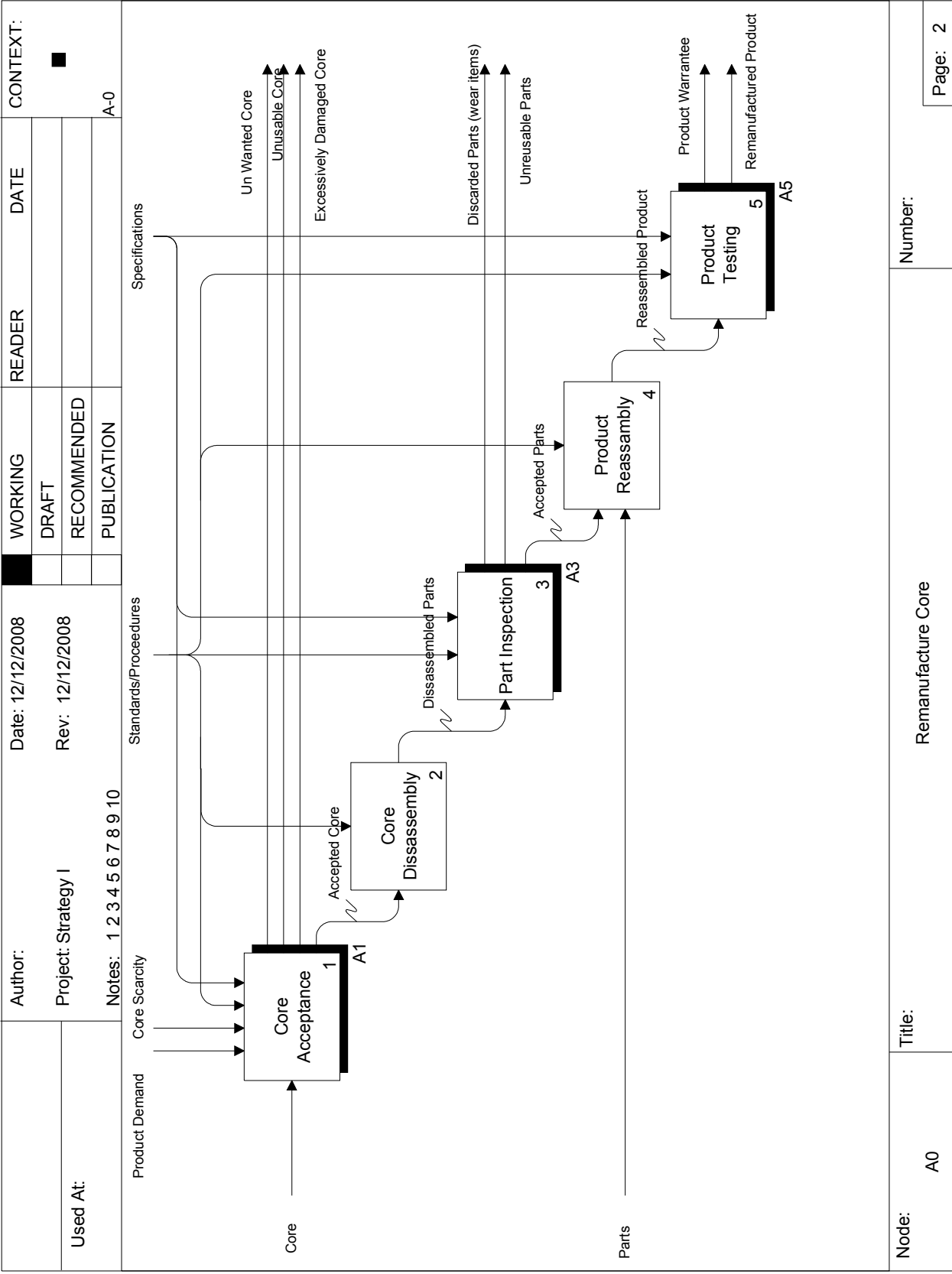
### **Strategy III**

This strategy relies heavily on discarding unsuitable cores in large numbers at the earliest possible stage. Cores that are un-sellable once processed perhaps due to their age and/or demand will be reject immediately. Borderline cases that do not pass a turn on test will also be discarded. Only those cores with high value fail the turn on test are analysed further. Faults are identified and those that are deemed economical to repair are processed. Disassembly is only carried out to the level required to replace the failed component or components. Cores are not routinely disassembled. Final product testing is used to ensure the product will function for a full second life.

### **Strategy IV**

As with Strategy II the main aim here is to assess the feasibility of the remanufacturing of a given core. Less emphasis is put on some of the inspection procedures however the performance inspection is critical for finding the faults with an item and in some cases providing a quote to the customer for the work. As with strategy III disassembly is only carried out in order to facilitate the replacement of failed components and final product testing is used to ensure the product will function for a full second life.

Appendix H. IDEF0 Diagrams for Strategies I-IV





Author:		Date: 12/12/2008		WORKING		READER		DATE		CONTEXT:	
Project: Strategy I		Rev: 12/12/2008		DRAFT						<input type="checkbox"/>	
Notes: 1 2 3 4 5 6 7 8 9 10				RECOMMENDED						<input type="checkbox"/>	
Used At:				PUBLICATION						<input type="checkbox"/>	
Standards/Procedures		Product Demand		Core Scarcity		Specifications				A0	
<div><div>Core</div><div>Visual Inspection1</div><div>Undamaged Core</div><div>Physical Inspection2</div><div>Usable Core</div><div>Identification Inspection3</div><div>Identified Core</div><div>Performance Inspection4</div><div>Accepted Core</div><div>Un Wanted Core</div><div>Unusable Core</div><div>Excessively Damaged Core</div></div>											
Node: A1		Title: Core Acceptance				Number:		Page: 3			

Author:		Date: 12/12/2008		WORKING	READER	DATE	CONTEXT:
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Notes: 1 2 3 4 5 6 7 8 9 10				RECOMMENDED			<input type="checkbox"/>
Standards/Procedures		Specifications		PUBLICATION			<input type="checkbox"/>
Used At:							<input type="checkbox"/>
							A0

Disassembled Parts

Identification Inspection 1

Known Parts

Performance Inspection 2

Unreusable Parts

Accepted Parts

Reconditionable Parts

Part Reconditioning 3

Reconditioned Parts

Discarded Parts (wear items)

Node: A3	Title: Part Inspection	Number:	Page: 4
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Author:		Date: 12/12/2008		WORKING	READER	DATE	CONTEXT:
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Notes: 1 2 3 4 5 6 7 8 9 10				RECOMMENDED			<input type="checkbox"/>
Standards/Procedures				PUBLICATION			<input type="checkbox"/>
Specifications							<input checked="" type="checkbox"/>
Used At:							

Reassembled Product

Performance Inspection 1

Failed Product Rework

Finished Product Rework 2

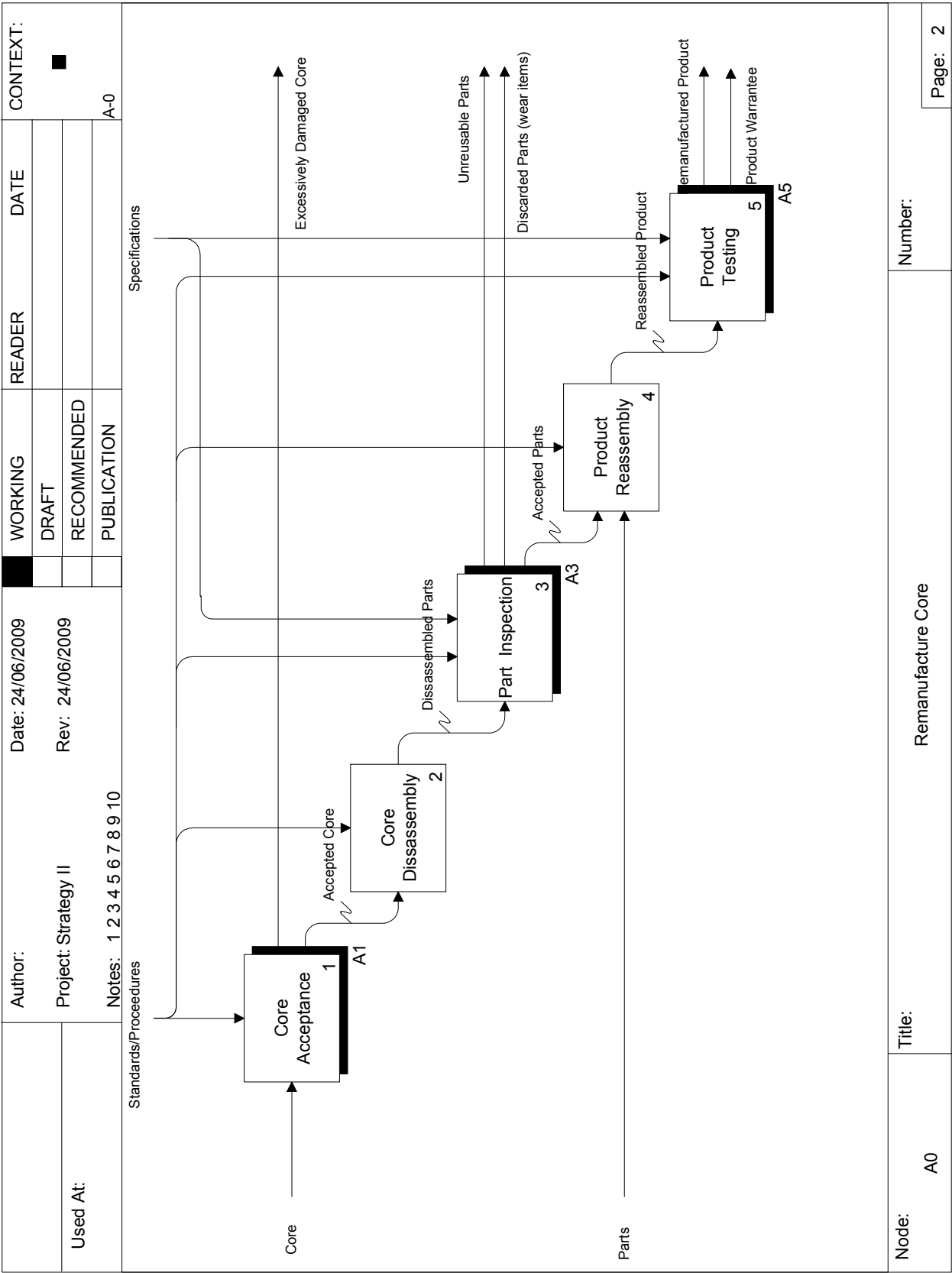
Reworked Products

Product Warranty

Remanufactured Product

3

Node:	Title:		Number:
A5	Product Testing		Page: 5







Author:		Date: 24/06/2009		WORKING	READER	DATE	CONTEXT:
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Specifications				PUBLICATION			<input type="checkbox"/>
Standards/Procedures							<input checked="" type="checkbox"/>
Used At:							

Reassembled Product

Performance Inspection 1

Failed Product Rework

Finished Product Rework 2

Reworked Products

Remanufactured Product

Product Warranty

3

Node:	Title:		Number:
A5	Product Testing		Page: 5

Author:		Date: 24/06/2009		WORKING	READER	DATE	CONTEXT:
Project: Strategy III		Rev: 24/06/2009		DRAFT			■
Notes: 1 2 3 4 5 6 7 8 9 10				RECOMMENDED			
Core Scarcity Product Demand		Specifications Standards/Procedures		PUBLICATION			A-0
<div><div>Core Acceptance1A1</div><div>Core</div><div>Accepted Item</div><div>Product Testing2A2</div><div>Parts</div><div>Un Wanted Core</div><div>Unusable Core</div><div>Excessively Damaged Core</div><div>Remanufactured Product</div><div>Product Warrantee</div><div>3</div></div>							
Node: A0		Title: Remanufacture Core				Number: Page: 2	



Author:		Date: 24/06/2009		WORKING		READER		DATE		CONTEXT:	
Project: Strategy III		Rev: 24/06/2009		DRAFT						<input checked="" type="checkbox"/>	
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Standards/Procedures		Product Demand		PUBLICATION						A0	
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Node: A1		Title: Core Acceptance						Number:		Page: 3	

Author:		Date: 24/06/2009		WORKING	READER	DATE	CONTEXT:
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Specifications		Standards/Procedures					A0
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Node: A2		Title: Product Testing				Number: Page: 4	

Author:		Date: 24/06/2009		WORKING	READER	DATE	CONTEXT:
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				PUBLICATION			A-0
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Node: A0		Title: Remanufacture Core				Number: Page: 2	

Author:		Date: 24/06/2009		WORKING	READER	DATE	CONTEXT:
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Standards/Procedures				PUBLICATION			<input type="checkbox"/>
Used At:		A0					
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Node: A1		Title: Core Acceptance				Number: Page: 3	

Author:		Date: 24/06/2009		WORKING	READER	DATE	CONTEXT:
Project: Strategy IV		Rev: 24/06/2009		DRAFT			<input type="checkbox"/>
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Used At:							A0
<div><div>Specifications</div><div>Standards/Procedures</div><div><div>Undamaged Item</div><div>Performance Test / Fault Finding 1</div><div>Failed Product</div><div>Product Rework / Repair 2</div><div>Remanufactured Product</div><div>Product Warrantee</div><div>Parts</div><div>Reworked Product</div><div>3</div></div></div>							
Node: A2		Title: Product Testing				Number: Page: 4	

## **Appendix I. Invitation to Take Part in Validation of Models**

Dear Sir/Madam,

Last year you may have received an email from Oakdene Hollins requesting your involvement in a research project we have been carrying out here at Exeter University.

The research has been looking at the role of inspection procedures within remanufacturing as well as other reuse processes. It aim was to find out the different stages and purposes of inspection and testing within organisations remanufacturing different projects. A large number of companies agreed to take part in the research and have provided useful and interesting insights.

A generic model, which describes the scope and purpose of each inspection process (for that of cores/returned products, parts and remanufactured products) has been produced along with more specific diagrams for different product characteristics. It is hoped that this can be used in order to assist the understanding of inspection procedures and ultimately lead to efficiency gains and cost reductions.

In order to improve the usefulness and relevance of my research, if it is possible, I would like to meet you to discuss the findings in general as well as those specific to your process. I estimate that our meeting would take approximately one hour. In exchange for your involvement you will receive free access to the models and I will travel to your site to meet you some time within the next 6 weeks.

If this is acceptable then please let me know (email [M.Errington@exeter.ac.uk](mailto:M.Errington@exeter.ac.uk)) and I will propose some dates for our meeting.

I hope that you will respond positively to my request.

Kind Regards

Mark Errington  
Final Year PhD Student – Operations Management for Sustainability  
School of Engineering, Computer Science and Mathematics  
Exeter University, UK

# Appendix J. Validation Questionnaire

## Questions About Your Organisation

If your organisation remanufactures more than one type of product please answer this questionnaire for only **one** of them. (you can use a separate questionnaire to give us details of another product if you wish.)

Name (optional):.....Job Title/Role:.....

Which project will you be answering questions on? (please be as specific as possible).....

Would you categorise this as an Electronic or Mechanical item?.....

Approximately how many of these items do you remanufacture per month?.....

Approximately what % of cores that you receive do you remanufacture and sell?.....  
(as appose to discard or recycle)

Which box do you think your process fits into in the matrix shown in the remanufacturing inspection Models document? (please circle)

I      II      III      IV      None      Don't Know

Please circle your answers on the following scale.

**Strongly Disagree**

**Strongly Agree**

Cores mainly arrive in a worn out state.

1      2      3      4      5      6

A large percentage of cores we receive are still fully functional

1      2      3      4      5      6

It is necessary to completely strip down and rebuild all of the cores we process.

1      2      3      4      5      6

## Questions relating to the Remanufacturing Inspection Models Document

The processes that have been described in the presentation closely match what is done in our process.

1      2      3      4      5      6

Core/Part/Product inspection presents a large cost to our organisation.

1      2      3      4      5      6

	Strongly Disagree			Strongly Agree		
Core/Part/Product inspection requires highly specialised skills.	1	2	3	4	5	6
There is currently <b>no</b> shortage of these skills.	1	2	3	4	5	6
Our company is allowed to modify the inspection procedures within our process..	1	2	3	4	5	6
The model assists my understanding of the role of inspection during our remanufacturing process.	1	2	3	4	5	6
The model looks like it has the potential to help me to make improvements to our process.	1	2	3	4	5	6
The model will help me to explain the purpose of inspection procedures to my colleagues and those new to my organisation.	1	2	3	4	5	6
Core/Part/Product inspection is an area with which we are <b>not</b> currently facing difficulties.	1	2	3	4	5	6

### Recommendations/Suggestions

Please use this space to note down any suggestions for improvements to the model.

Do you have any suggestions for further extensions to the model or this research which you would find useful?

Thank you for taking the time to answer these questions. This type of feedback is vital to ensure that research carried out by our department is relevant and useful to industry.

If you would like more details about this research and/or find out the results from this survey please note your email address below.

Email (optional) .....



## **Appendix K. Validation Case Study Notes**

### ***ClothesCo***

ClothesCo is a small business based near Leeds University. Their mission is to divert textile from waste by making then into individual, bespoke and fashionable items. In order to do this the business makes its own clothes for resale, from discarded fabric and clothes, but also runs workshops training others how to do it. These notes do not cover the workshop side of the business. The clothes are sold through many outlets including market stalls, festivals, workshops, websites and shops. Some of these are operated by ClothesCo whereas others are not.

### **Core Return**

Unwanted textiles are donated to ClothesCo directly from the public. Their location in a university town means they receive donations at specific times of year. They also source materials from charity shops and other locations. Purchases from charity shops are based on specific needs whereas donations are often unsolicited but nonetheless very useful. The input material consists of curtains and unused fabric as well as complete clothing. Some clothing is stored in the anticipation that it will become fashionable again whereas other clothing is repurposed as follows.

### **Inspection Processes**

Core level inspection is largely done by eye and experience. Materials that are used are assessed for quality, feel and other characteristics. As one of the stated aims of the organisation is to minimise textile waste the amount discarded at this point is very low indeed. It may also be the case that a customer requires a specific piece of clothing to be used. Following the physical assessment of the materials, the potential for use is accessed. There is no formal process for this but it relates to how well items made from similar designs and materials have sold in the past.

Textiles are cut, shaped and sewn into a new garment. Additional new material is used for zips and fasteners etc to ensure longevity. There is no formal inspection during this process however attention is paid during sewing to ensure materials are of sufficient quality. Once the clothes have been made items are worn by staff for a period of time in order to ensure durability. Those that fail these tests are rethought or reworked into different items. Those that pass are made available for sale using the routes described above.

### **Other Notes**

The company is based in what is ultimately the most fashion conscious industry. This is not a common place for remanufacturing companies to be found. Items that are produced are fundamentally different to the items that are used and command much higher prices. It is often the intention of the design to make clear that the item has been made from old textiles. Examples of this include shorts and skirts made from cartoon character printed bed sheets and a leather jacket made from a leather sofa. The fact that they are made from old textiles adds to the value in itself. The phrase repurposing would appear to fit more closely to the description of this process than remanufacturing. The process fails to fit neatly within the model that has been developed. It is thought that this may be due to one or more of these factors.

## **CompressorCo**

CompressorCo are a small 3<sup>rd</sup> party remanufacturer of compressors based in southern England. They remanufacture most makes & types of compressors for use in the refrigeration and air-conditioning industry. These range from fractional up to around 120 hp in terms of their power output. Fully hermetically sealed compressors are not remanufactured.

Once a compressor fails in the field it is removed by a highly skilled technician and returned to CompressorCo. The technicians are either employed by the owner of the equipment or the task is subcontracted.

All compressors that are returned in this way are either worn out or have failed during use. Cores are held in stock and when ordered are passed through the remanufacturing process. Skilled technicians then install the compressor.

The price of a remanufactured compressor is typically 50% of the cost of a new unit. For rare cores a quote for the work is given to the customer prior to the compressor being remanufactured.

Replacement parts are now sourced from OEMs as well as 3<sup>rd</sup> party producers. OEMs have not always been this cooperative. Until recently they saw 3<sup>rd</sup> party remanufacturers of their equipment as a competitor however they now compete within the spare parts supply market. In the compressor remanufacturing industry unprocessed cores are referred to as 'dead bodies'

## **Inspection Procedures**

It was commented that the major cost of remanufacturing in the compressor industry is the purchase of replacement parts.

It was agreed that the inspection procedures fitted most closely with strategies I and II. The value of the casing is such that only cores which have casings damaged beyond repair are uneconomical to remanufacture. This would be consistent with strategy II feasibility based core acceptance decision however a limited number of cores may also be scrapped if there is insufficient demand. For this purpose there is an identification inspection step as well as a visual inspection. Once core inspection has been carried out the cores will normally be held in stock until an order is received. This is the so called disassemble to order strategy.

## **CoreCo**

CoreCo is a core broker supplying automotive cores to the remanufacturing industry throughout Europe.

### **CoreCo Inspection Procedures**

Cores are inspected before they are purchased, after they arrive in the warehouse and finally when the core is sold to a customer. The steps through which the core is accessed are the same at each of these three stages. This is termed 'scratch and sniff' in the industry. Signs of obvious damage are looked for, the part is identified and some sort of physical inspection is carried out. Scratch to clear off grime to identify the part and sniff to see if the unit is burned out. These processes mean that only 5% of cores that are supplied to remanufacturers are subsequently found to be unsuitable for remanufacture. Considering the lack of equipment and disassembly this is an impressive achievement.

It was stated that one of the reasons why the cores must be inspected so many times is the fact that they can be very difficult to identify.

## **AltCo Case**

AltCo is a remanufacturer of rotary electrics based in the UK. They remanufacture approximately 10,000 units per month and operate using the so called bang bang approach of processing all cores using the same process.

### **Core Return**

AltCo uses cores that are supplied by core brokers.

### **Inspection Procedures**

AltCo processes cores in much the same way as described in strategy II. They do not scrap whole cores due to the fact that they have been purchased and the core broker has already carried out all possible core level inspection processes. The core is disassembled, some parts such as bearings are always replaced, other parts are inspected before reuse. AltCo has a general rule that if it can't be tested then it is replaced.

Required parts are replaced and the products are reassembled. Testing is carried out on finished products before they are packaged and sold to the customer. AltCo uses 1.5-2 to one remanufacturing where possible. This where more than one core is used to make one final core. Fewer parts require replacement using this strategy which reduces costs.

It appears on the surface that AltCo uses a strategy II inspection procedure. On closer inspection, it appears to be a Strategy I process with the core broker carrying out the majority of tasks in the core level inspection procedures. This is interesting since it shows that there are opportunities for creative guarantees. All of the cores that are supplied by CoreCo are not working however they guarantee them to be fixable. Any faults that should have been spotted at a core level that were not can result in a claim against CoreCo.

## **FlightCo**

FlightCo was established in 1955 manufacturing pins and rivets. They have been based at their present location since 1972 and currently employ 285 employees. Currently they mainly manufacture turned components for aerospace, defence and associated industrials. Some work is still done for commercial customers however quality demands from the aerospace industry make them uncompetitive in this area.

A small part of the business is the repair and overhaul of aerospace subassemblies. As aerospace component manufacture becomes more competitive the company is looking to expand its much more profitable, but currently very small, remanufacturing processes.

### **Core Acquisition**

Cores are supplied by customers wishing them to be remanufactured. Each core must be returned to the customer that supplied it. FlightCo remanufacture other company's products as well as their own.

### **Inspection Procedures**

Before a core is disassembled a brief check is made to insure that the unit delivered is the one that was expected. Any obvious sign that would make the unit unusable is also looked for here. This only includes damage which would make the unit completely beyond repair.

The unit is then disassembled and each of the parts is performance inspected against certain criteria. This includes number of flying hours, viable damage and wear, measurement of diameters etc and for some parts a leak test. Once the extent of the work required is known a quote is given to the customer. Typically if this quote is less than 2/3 of the cost of a new unit then the quote will be accepted. It is only after this quote is accepted that further work is carried out. In practice it is very rare for the work to not be carried out.

Replacement parts are obtained from the component manufacturing side of the business where possible. Other parts are bought in from other companies. Approximately 20% parts require rework and other treatments before they can be reused.

Once all parts are available the core is reassembled. A test rig is used to extensively test the product before it is returned to the customer. Tests are carried out in accordance with pre approved air-worthiness release procedures. Where necessary fault finding and rework are carried out in order to bring the equipment within specification.

## ***RetailCo***

REMOVED AT REQUEST OF INTERVIEWEE

## ***TonerCo***

TonerCo is a remanufacturer of laser printer toner cartridges based in the south of England. They remanufacture around 700 units per month and sell to retailers. It was stated that it takes approximately 6-12 months for the cartridge remanufacturing industry to develop processes to remanufacture a newly developed cartridge.

## **Core Return**

Cores arrive at TonerCo from core brokers.

## **Inspection process**

Cores are inspected at core level. If the casing of the cores is damaged then they are rejected. Cores are also rejected if they are not either OEM or remanufacture by TonerCo. This is due to the fact that the quality of the components used to remanufacture the cartridge is not known. Cores that there is not currently a demand for are either put into stock or rejected. In total 90% of cores received are remanufactured. A print test is carried out on the cartridge. If it is found to work then the cartridge is disassembled. If it does not work then fault finding is undertaken before disassembly.

Once disassembled the components are inspected for damage and tested against specification. It is known how many times OEM parts can be reused before they fail, it is also known how many times parts supplied to TonerCo can be reused. This information is used to determine which parts should be replaced before the cartridge is reassembled. If required cartridges can be upgraded during this process for example to hold more toner.

After reassembly the cartridge is tested in a printer before it is repackaged and made available for sale. TonerCo experiences a return rate of approximately 1%.

## **VacCo**

VacCo is a manufacturer of high vacuum pumps for business customers. The pumps are commonly used in processes such as semi conductor and solar cell manufacture. They have the capability to reduce pressures close to ultimate vacuum. They operate in a vast array of different conditions and have an initial life span of 3 months to 5 years depending on these conditions.

VacCo have been carrying out remanufacturing on their own products for over 20 years. Approximately 20% of the £5M business is currently in remanufacturing of existing pumps. Currently VacCo remanufacture 45,000 different product types, all of which they manufactured originally. Globally they process over 4000 units per month. This ranges from small gauges to multiple pump systems. VacCo operate a large number of hubs globally which carry out remanufacturing operations. Despite the fact that they are the OEM of the products they remanufacture, VacCo still state that parts are their biggest cost.

## **Core Return Path**

Companies that use vacuum pumps can have up to 2000 pumps on one site. For this reason they often have highly skilled technicians who remove the pump before it is returned to VacCo. If such technicians are unavailable then pumps are removed by VacCo technicians. Due to cost pressures, the majority of pumps are run until they crash (fail or fill up of process material). Many systems run with multiple redundancy and a lot is known about when they are likely to crash. This minimises negative impacts when the pumps crash. Due to the environments in which the pumps operate they are received in a vast array of different conditions. In some cases metal can be eroded from one part of the pump and deposited elsewhere causing it to crash.

## **Inspection Procedures**

On arrival at the local facility the core acceptance procedure largely follows the generic process. First of all a visual inspection is carried out in order to assess major damage. A physical inspection is carried out to identify if any parts are missing. Digital photos of the core are also taken at this point. The identification inspection is more detailed than has been observed in other processes. It is essential for safety reasons that the core that is returned is the exact core that is expected. The way a core is handled depends on the substance with which it has been working. This is specific to each individual pump. No performance inspection is carried out as such while the core is still hole.

Once the core has been disassembled each part is judged against performance criteria to assess its suitability for reuse. By this point one third of the labour costs associated with remanufacture have been spent. This performance inspection stage has an additional purpose which is to assess any warrantee claims against the product. The performance specifications against which the parts are judged are specific to the level of service required by the customer. Reconditioning is carried out on some parts in order to bring them within specification.

Once the parts have been reassembled into a product the unit undergoes a performance inspection. Once again the specifications for this differ by product and use. Some units are known to perform very badly indeed during factory testing that work as required when they are installed and an amount of material enters them. Following final testing the units are returned to as received configuration.

It was commented that although this is the common route for a large number of products there are some that differ. VacCo carries out warrantee repair and equipment service where the same unit must be returned to the customer, it also processes commercial returns and carries out remanufacturing to supply customers with units that they do not already own.

During the interview it was noted that services and warrantee returns fit more closely with strategy II since the unit must be processed and returned. Where units are remanufactured to stock the process fits more closely to strategy I. Commercial returns on the other hand appear to be processed according to strategy IV where no routine disassembly is carried out. The electronic control part of the assembly, once separated from the rest of the core is processed using a strategy III approach. A visual check is made followed by a series of tests.

An interesting point made during the meeting was that customers have different expectations for how the unit should look depending on if they buy a remanufactured unit or have their existing unit processed. Casing dents that would be acceptable if it is the same product returned are unacceptable if a 'new' remanufactured product is supplied.

## **WasteCo**

WasteCo is a WEEE processor based in Boston, UK. Their stated mission is to maximise value from waste. They are also a member of ICER the Industry Council for Electronic Equipment Recycling. They currently claim to have the provide the most viable form of WEEE recycling both environmentally and financially. They do this by reselling a large amount of the equipment they process and also carry out manual disassembly in order to maximise purity and in turn revenues from the recyclates they produce.

## **Core Acquisition**

WasteCo hold contracts to treat WEEE from Civic Amenity sites in the local area. They provide storage and collection equipment in order to minimise damage during the period from when the equipment is dropped at the CA site by the end user and when it arrives at their facilities. The largest volume product that WasteCo deals with currently is CRT TVs. For this reason this was the case that was studied in most detail for this document.

## **Inspection Procedures**

As equipment is unloaded from transport containers it is sorted into two piles. Items that have a positive resale value and those that are un-reusable. Items may be un-reusable if they are heavily damaged in transit or if there is no demand for them due to their age. Those which are considered un-reusable constitute the majority of items which are received. Those items which show potential for reuse are first put through a standard PAT (Portable Appliance Testing) which is required by law before the equipment is put through further tests. These tests are specific to the equipment. In most cases the first step is a turn on test. Following this tests are carried out to assess the likely remaining life of the equipment as well as its full functionality.

Equipment that fails these initial stages of testing is assessed for value once working. If viable then equipment is repaired as necessary. If infeasible for repair the items are recycled using the process described above.

All working equipment is either sold within the UK through WasteCo store, where it is sold with a warranty at approximately 50% of the cost of new, or bulk shipped to countries where it has more value. All equipment is processed to order and is shipped as soon as it is available. In order to prove that the company is acting responsibly and to 'convert' waste back into products they must demonstrate that it is fully functional and safe to use.

Where ever possible parts are recovered from other equipment to facilitate repair. With equipment such as vacuum cleaners the following many to one remanufacturing approach is followed.

Equipment of a certain type and make is left to accumulate for a period of time. Once sufficient equipment is possessed it is inspected and repaired by exchanging parts between units. The non functional equipment that remains is disassembled and recycled. The working products are returned to the market.



## Appendix L. Validation Questionnaire Responses

Company	Role	Product	Electronic / Mechanical	Volume/month	% used	Strategy	worn out?	fully functional ?	complete strip down
CompressorCo	Marketing Admin	Compressors	Mechanical	200	95	I	5	1	6
VacCo	Global Support Manager Remanufacturing	H. Vacuum Pumps	Both	4300 (worldwide)	90-95	All	4	2	6
WEEECo / WasteCo	Chairman	Televisions (also processes all WEEE)	Electronic	4000	15-20	III	2	3	1
FlightCo	Quality Manager	Aerospace Flight Control Units	Mechanical	2-3	99	II	4	3	6
RetailCo	Technology Manager	Kettle	Electronic	0	NA	III	5	2	NA
RetailCo	Technology Manager	LCD TV	Electronic	0	NA	IV	2	5	NA
ClothesCo	Designer/Director	Remade Cloathing	Neither	20-30	85	I & IV	2	6	5
TonorCo	Ex-Production Manager	Toner Cartridges	Mechanical	700	90	I	5	1	6
GearCo	Commercial Director	Manual Transmissions	Mechanical	1200	99	I/II	5	2	6
AltCo	Managing Director	Rotating Automotive Electrics	Mechanical	10000	80	II	6	4	6

Company	Match our process	Inspection costs a lot	Inspection is high skill	No shortage of skills	Company can mod	model assists my understanding of inspection	the model has potential to improve our process	the model will help to explain inspection	not currently facing problems with inspection
CompressorCo	5	2	5	2	5	5	2	1	6
VacCo	6	2	4.5	4	5	4	4	5	2
WEEECo / WasteCo	5	2	2	5	5	4	3	5	5
FlightCo	4	3	5	2	6	5	4	4	5
RetailCo	NA	NA	6	2	5	5	5	5	2
RetailCo	NA	NA	6	2	5	5	5	5	2
ClothesCo	2	2	5	6	6	6	6	6	6
TonorCo	5	4	3	4	2	5	3	5	2
GearCo	5	3.5	5	5	5	3	3	3	5
AltCo	5	3	3	5	6	4	3	5	5

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